Binocular rivalry and top-down attention: Effects of action intention and learning

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– Wer keinen neuen Anfang wagt, dem bleibt nur das alte Ende. –

(Chin. Sprichwort)

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Zum Gedenken an meinen Vater

– Dad, trotz allem, doch geschafft!

Contents

Summary

When the two eyes are presented with two incompatible images, the observer perceives a stochastic alternation between the two images, a phenomenon called binocular rivalry. One question is whether top-down cognitive processing can influence the alternation of rivalry. In the literature, top-down effects were mostly tested by instructing observers to pay attention to a certain stimulus. Thus, mainly one function of attention had been tested: perceptual selection. But it is still an open question whether other functions of attention may influence rivalry. Because attention mediates cognitive processes such as perception and action, or learning and recognition, top-down attentional effects on binocular rivalry were investigated. An action intention and a learning paradigm.were employed.

In experiment 1 (action intention experiment) participants were to build an action intention during the rivalry experiment. The action intention`s influence on the initially perceived stimulus, the frequencies of dominance of the target percepts were tested and clear effects could be found.

In experiment 2 (learning experiment) participants learnt an acoustic cue and a Chinese character as a pair-associate. When cued during rivalry, participants were to check the Chinese character. Effects on the initial percept and on the frequencies of target percepts were found. Further, longer phases of target percepts could be revealed.

For both paradigms results indicate top-down processed attention as a mediating variable affected the initial percept at the onset of rivalry and the dominance of the targets, respectively. Results of the two experiments are compared and discussed.

1 Introduction

In humans the left and the right eye fields overlap to some degree. Looking at the same object, information of corresponding points of the two retinae is processed to finally build a unified image. This image helps humans to accurately generate visually guided behavior. But what happens if the eyes are presented with two incompatible stimuli? Instead of seeing a mixture of both, the observer perceives the two images stochastically alternating in cycles of some seconds – a phenomenon called binocular rivalry. But can rivalry be influenced? By changing the physical aspects of one of the two stimuli (e.g. contrast, brightness), one affects the alternations in a data-driven, bottom-up manner (Mitchell et al., 2004). Cognitive, top-down effects on binocular rivalry have also been shown, usually by requesting observers to pay attention to a certain stimulus (Ooi and He, 1999, among others), a function of attention known as perceptual selection (Müller and Krummenacher, 2002). Still an open question is if other functions of attention, namely its mediating role in perception and action, or learning and recognition, may also influence binocular rivalry.

The present experiments investigated the role of top-down attentional processing in rivalry. The first experiment (action intention) used tools and tool images as stimuli, while in the second experiment (learning) a Chinese character had to be learnt, which was subsequently tested in a binocular rivalry experiment.

To understand binocular rivalry in more detail, information about the visual pathways and binocular vision is given in chapters 1.1. and 1.2. Chapter 1.3 introduces binocular rivalry more precisely and overviews the field of bottom-up and top-down attention approaches on rivalry. The objectives of both experiments are discussed in more detail in chapters 2 and 3 respectively, followed by the experiments and their discussions. In part 4 (General Discussion) the results of the two new applied paradigms on rivalry are compared and discussed.

1.1 The visual pathways

After passing different components of the eye (cornea, lens, vitreal chamber) light rays finally reach the *retina* with its anatomical and functional different cell layers. First light rays have to pass various types of ganglion cells, the inner plexiform layer with amacrine cells, bipolar cells, the outer plexiform layer with horizontal cells to finally reach the photo receptors of which two different kind exist – rods and cones. In this early stage of vision one can identify amazing, but rather complicated information processing in all layers of the retina – even in the two interneuronal systems of the two plexiform layers a complex modulation and further processing is observed (Eysel, 2001; Purves, Lotto, 2003).

In the human retina one finds approximately 120 million rods and 6 million cones. Rods have high sensitivity, are exclusively distributed in the periphery, and have a broad spectral tuning. In contrast, cones have lower sensitivity, are highly concentrated in the fovea, and one can differentiate three types of spectral tuning to guarantee color perception.

While information is processed by receptor potentials in nearly all of the above named cells, all-or-none action potentials are first found in the ganglion cells. These cells also have *receptive fields*. A receptive field of a neuron is the part of the visual field resp. the retina in which an adaequate stimulus leads to a change of the neuron's activity. Ganglion cells' receptive fields are concentric with excitatory inner region and inhibitory surrounds or vice versa (ON-center, OFF-center). In primates, ganglion cells are not homogenous, instead, are classified into achromatic magnocellular M-cells, color-opponent parvocellular P-cells and a heterogenous group. This segregation is maintained up to the visual cortex. But all ganglion cells' fibres form the optic nerve, going to the *optic chiasm* where a hemidecussation allows the nasal parts of the retinae to project to the contralateral side of the occipital cortex. (Thus, the right visual field is completely represented in the left occipital cortex and vice versa.) After this partial crossing the now called *optic tract* sends information to the *lateral geniculate nucleus* (LGN). This nucleus is strictly organized: each of its six layers receives input from only one eye or the other and moreover differ in

neuron size. Two layers contain larger neurons (magnocellular layers), while the other four contain smaller neurons (parvocellular layers) (Bear et al., 2001). Achromatic ganglion cells of the retina project to the magnocellular layers, neurons from the ipsilateral eye go to layer 2, those from the contralateral eye to layer 1. This magnocellular system is mainly concerned with motion information processing, because it has larger receptive fields and is faster. Color-opponent cells send their fibres to the parvocellular layers, ipsilateral to layers 3 and 5 and contralateral to layers 4 and 6. The parvocellular system processes color and form (Bear et al., 2001). Corresponding areas (see chapter 1.2.1) of the two eyes are coded in projection columns running perpendicular to the six layers.

What is known about binocular responses of that nucleus? Indeed, there is conflicting evidence about binocular processing in the primate LGN. But in their study Schroeder et al. (1990) revealed several basic types of binocular interaction affecting both parvo- and magnocellular layers in alert maqaques. Binocularity was found in nearly all layers (except 4), inhibitory effects included binocular suppression during binocular stimulation of the dominant eye, non-dominant-suppression during stimulation of the non-dominant eye – these effects often preceded the excitatory response of the stimulated dominant eye. According to the investigators early responses in the LGN are not influenced by feedback from V1.

From the LGN the optic radiation spreads to *primary visual cortex (V1)*. Again one finds six layers functionally highly organized: separate input of the two eyes coming from the geniculate nucleus projects mainly to layers 4 with all its subdivides. Some of the cells show similiar receptive fields seen in the retina, but others consist of a strip (excitatory or inhibitory) flanked by other strips (inhibitory or excitatory). These cells serve as line-detectors (Carpenter, 2003). Taking the receptive fields' behavior into account one can broadly classify these cells in simple, complex and hypercomplex (nowadays referred to as end-stopped). Simple cells respond to small spots of light falling on their receptive fields, complex cells to bars or edges of specific orientation, and end-stopped cells respond not only to orientation, but also to a certain length of a stimulating bar or line (Carpenter, 2003). Orientation tuned cells are functionally grouped

in columns running orthogonally to the surface. Each column receives input from one or the other eye, thus is right-eye-dominant or left-eye-dominant. Columns of the same dominance form another structure called hypercolumn. Within a hypercolumn one can identify blobs, structures which contain monocularly driven, wavelength-responding neurons, and inter-blobs with good tuning to high spatial frequencies, binocularity, and orientation selectivity (Farah, 2004). While simple cells are excited by only one eye, complex cells are normally driven binocularly – some of them have receptive fields with corresponding areas in each eye, but some of them with pairs of receptive fields that do respond to not exactly corresponding areas (disparity-detecting cells, see section 1.2.1 for details). Layer 4B, blobs and interblobs send their signals in two pathways to V2, V3, V4 and MT (middle temporal area). In 1992 Goodale and Milner originally prosposed two different functions underlying these two pathways. The ventral pathway (from V3 to areas V4, V8 (in humans) and IT-inferotemporal cortex (Neri, 2004)) leads to the temporal lobe and is mainly concerned with object recognition, the other so-called dorsal pathway from V3 to areas V3a, V7 (in humans), V5/MT and MST (Neri, 2004), and leads to the parietal lobe and is known to process spatial information (Purves et al., 2001). Not long ago it seemed that the segregation into magnocellular and parvorcellular systems one can observe in the geniculate nucleus is maintained when these pathways ascend to higher visual areas (Livingstone, Hubel, 1988). It was believed that the dorsal (magnocellular) pathway is exclusively processing spatial information, while the ventral (parvocellular) pathway processes object recognition. But recent research shows a complex intermingling of information: the dorsal pathway also receives information from parvocellular streams and vice versa (Purves et al., 2001; Horton et al., 2004). The result of these two mutually influencing systems is interlocked information processing of perceptual and action events.

1.2 Binocular vision

When humans keep the head and eyes stationary their *monocular fields* amount to approximately 95 ^{o} in the lateral (temporal) direction and about 56 ^{o} in the the nasal direction for each eye. Within each monocular *field* one finds a binocular overlap. The two lateral fields which can only be perceived with each eye respectively extend about 37^{0} – these strictly monocular areas are adressed as *monocular sectors*. The *binocular field* (the part of the visual field where objects are seen by both eyes) spreads over 114^{0} when the eyes converge symmetrically. Finally, with stationary eyes the *total visual field* in which objects are seen by either eye or both extends 190^{0} .

The term „binocular vision“ usually refers to a large binocular field which codes depth information. But it is not only depth which is perceived better with both eyes open; the same goes for detection, discrimination of objects, and resolution (Howard, Rogers, 1995). On the other hand „stereoscopic vision“ means the perception of the three-dimensional world, no matter if one looks binocularly or monocularly. The brain is able to identify depth even from monocular cues like shading of objects, motion parallax, or occlusion to name only a few. But there are two exclusively binocular cues to depth which are the vergence position of the eyes and binocular disparity, both of which important for binocular correspondence.

1.2.1 Binocular correspondence

In binocular rivalry two incompatible images project to corresponding points of the two retinae. But how is binocular correspondence be defined? When one fixates an object the two eyes have slightly different positions to each other in their sockets, this is what is meant by *vergence positions*. On the basis of this information the human brain is able to infer how far the fixated object is. When looking at an object closed by, every eye has a slightly different view of this object due to the horizontal separation across the face which amounts to approximately 65 mm in humans. Thus, for geometrical and optical reasons the

two images on the two retinae differ slightly – this difference is called *binocular disparity*. (Mostly referred to is the horizontal disparity, which are sido-to-side differences in the similar images of the two eyes. For further discussion of other forms of disparities cf. Howard, Rogers, 1995). Binocular disparity increases the nearer and bigger an object is to the observer.

On the binocular portion of the retina one can geometrically, anatomically, or psychophysically define anatomical points which have a corresponding counterpart on the binocular portion of the other retina. When images in the two eyes fall on corresponding points they are thought of having *zero binocular disparity*, when these images further are very similar, one perceives a single object. When images fall on non-corresponding points one sees two objects. There are many such corresponding points and it is possible to mathematically define the locus of points in space that can project images to the corresponding points of our retinae. Such a locus is the so-called *horopter* (see figure 1). The horopter is a theoretical circle which passes through the point of fixation and the eye's nodal points (where all light rays are bundled and spread to the retina). The left side of figure 1 shows the geometry of a fixated object lying on the horopter, all points in space that stimulate corresponding points on the retinae (here shown in purple and brown) are perceived as having the same distance from the observer.

If an object within the horopter is perceived (shown in the middle) the stimulated point on the retina is temporally displaced from the geometrically corresponding point f' of the fixated object (*crossed disparity*). The object is perceived as being nearer than the fixated one.

An object outside the horopter (*uncrossed disparity*) is perceived to be farther away (shown on the right of figure 1).

Corresponding points (see f' in figure 1) can be defined by ascertain the radial and meridional congruence of the two retinas (*geometrical correspondence*).

In a *physiological* sense corresponding points are those which project to the same binocular cell in the primary visual cortex (V1). Thus, one finds a correspondence between the receptive field of a cortical cell in one eye and the receptive field of a cortical cell in the other eye. Interestingly, there exist

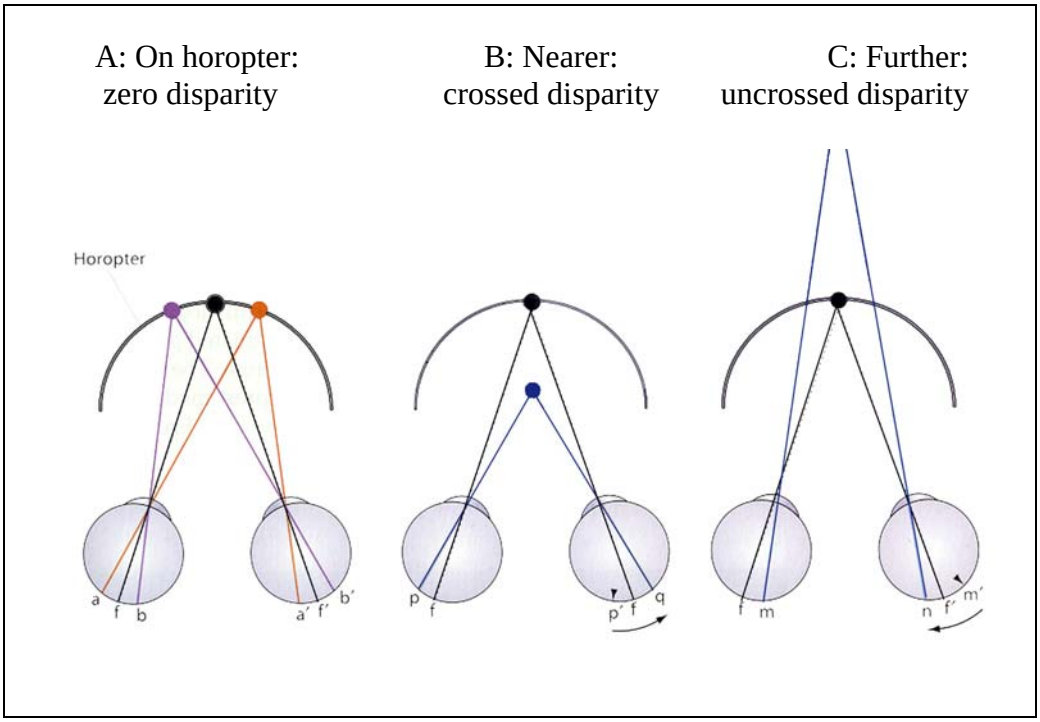

Figure 1: The horopter and its relation to the corresponding points in the two retinae. A: zero disparity, B: Crossed disparity and C: uncrossed disparity. (Diagrams in: Purves, Lotto, 2003)

cortical cells in V1 which answer to non-corresponding images – therefore working as disparity-detectors. Recent research revealed a possible contribution of V4 and V5/MT in processing of disparities (Neri, 2004).

Psychophysical correspondence of points can be found empirically by presenting participants with similar images which have to meet a psychophysical criterion, e.g. such as the nonius alignment (a common procedure to monitor eye movements). In rivalry research investigators usually refer to psychophysical or physiological correspondence.

Empirical findings show that all objects outside a horopter produce separate images, but on the other hand a range of disparities exist, within which similar images, one presented to each eye, are perceived as a single object. This range is known as the *Panum's fusional area*, and images „falling" within this area are considered to be fused images. Panum's area is not a constant, but rather depends on several factors such as retinal eccentricity, characteristics of the stimulus and surrounding stimuli (Howard, Rogers, 1995). If in contrast to this

the image falls outside Panum's area, one experiences a double image. But what happens if two dissimilar images fall directly on or close to corresponding points in this area?

1.3 Binocular rivalry

If humans are presented with two dissimilar images, one in each eye, they do not perceive a fused image, but instead experience an alternation of the two images, a phenomenon known as *binocular rivalry*. A stimulus which is currently seen is called „dominant“, while the other one is defined „suppressed“. It is clear that this phenomenon raises a lot of questions. Do any stimuli induce rivalry when presented in a proper way? The answer is a clear no, for it has been shown that stimuli designed with very low contrast fail to induce rivalry (see Liu et al. 1992, among others). The same goes for stimuli which flicker very rapidly (O'Shea, Blake, 1986).

On the other hand rivalry is induced by creating a difference between the left eye's and right eye's image concerning spatial frequency (Fahle, 1982), motion (Moutoussis, 2005), orientation (Tong, Engel, 2001), and finally by presenting participants with completely different pictures, e.g. a house and a face (Tong et al., 1998).

The temporal dynamics of image switching not only differ from person to person, but durations of an image to be dominant often follow a gamma distribution (Borsellino et al., 1972, Murata et al., 2003, Mamassian et al., 2005), the reason for this is not yet understood (Mamassian et al., 2005). Already many years ago the timing of binocular rivalry and its inherent phases attracted researchers. About a hundred years ago Breese (1899) observed that if both rival images are equal in their physical aspects, each image is dominant for approximately 50 % of the time. When he increased the luminance of both images equally, the rivalry process tended to speed, but interestingly, total dominance durations were maintained! This is an important observation, because it reveals that the selection process for one or the other image is different from the process which steers the alternations. Another landmark on binocular rivalry research came from Levelt (1965) who found that dominance durations throughout a trial follow a gamma distribution and that dominance and suppression behavior seem to follow inherent laws, grounded on the relative strenghts of the stimuli.

It is impossible to predict how long exactly a stimulus will be dominant, but there are variables which prolong the predominance of a certain image. Predominance is the total amount of time or the total percentage of time a stimulus is consciously perceived during an experimental trial. As Mueller and Blake (1989) have shown the predominance of a stimulus might be influenced by manipulating its contrast. As these two investigators found out it is the suppression phases of the high-contrast stimulus which become shorter and thus lead to an increase of predominance. In his experiments Levelt (1965; 1966) showed that two high-contrast rival stimuli „speed“ their alternations while two low-contrast stimuli show a decrease in alternation rate. But predominance might also be enhanced by changing stimuli' s luminance (Levelt 1965) or spatial frequency (Fahle, 1982). The influencing variables that „force“ a stimulus to become dominant described so far, strengthen its physical features. Now we turn to the question if meaning might help a stimulus to increase its dominance.

In his review Walker (1978) addresses the question whether a meaningful content affects the dominance of a stimulus. He reports an experiment carried out by Engel (1956; in Walker, 1978): Participants were presented with two portraits, one of which inverted. Participants reported more dominance of the upside-down portrait than of the inverted one. This and similar results (Toch, Schulte, 1961) showed that it might not only be physical properties of an image which forces an image to dominance but also cognitive components.

1.3.1 Theories of Binocular Rivalry – Bottom-up versus Top-down

Despite an extensive research had been done the nature of the two images' competition to be observed in binocular rivalry is still unknown. Some researchers change the physical appearance of a stimulus to see whether this would force dominance while others try to affect the alternations by investigating meaning and context of a stimulus. The first approach is considered as being driven *bottom-up*, that is the process in which information of one image is suppressed at the earliest stage of excitatory binocular

interaction (see Crewther et al., 2005, for a discussion). Usually the anatomical site for this processing is considered to be the primary visual cortex V1 (Koene et al., 2007; but see Freeman et al., 2005).

The other approach is considered to be the other way round: in *top-down* driven rivalry one finds high-level brain processes (e.g memory, meaning, etc.) which – metaphorically speaking – run top-down to the visual pathways and affect rivalry. The two, now top-down influenced representations of the images or stimuli are thought to compete for visual awareness at a given time.

Thus, if one translates the two arguments into a physiological language, bottom-up processes would reflect a neural competition either among monocular channels (interocular competition) or among pattern representation after the two eyes' inputs have converged in V1. Whereas top-down processes drive selection mechanisms for one or the other high-level representation on the basis of executive frontal-parietal brain processing (Tong, 2001) or inferotemporal cortex where categorization takes place (Crewther et a., 2005).

Why is it so difficult to unify all results into a single theory? While it is a fact that each approach has its difficulties to give sufficient explanations for <u>all</u> results investigated, there is on the other hand strong evidence which confirms both the bottom-up and the top-down paradigm.

<u>Bottom-up approach</u>: interocular competition / pattern competition

Lehky (1988) proposed an *interocular competition* model in which the core assumption states a neural competition between monocular channels. If the input to one eye is stronger than the other it excites inhibitory neurons which subsequently suppress the input of the other eye. When this eye adapts over time the dominance fades away and the former suppressed eye becomes dominant. Lehky (1988) further proposed inhibitory feedback from the primary visual cortex (V1) to the monocular layers of the lateral geniculate nucleus (LGN) as the functional anatomical site. Blake (1989) suggests an alternative by assuming monocular and binocular neurons to be functionally unified in modules. In his model monocular neurons are crucial to signal stimulus conditions and – beginning as local processes – give rise to suppression over the entire cortical representation in the binocular field. There is indeed evidence

to support the interocular view. Blake, Westendorf, and Overton (1980) presented their participants with two images and during a dominance phase of a certain stimulus rapidly swapped the two stimuli between the eyes. They found that the eye which perceived the former dominant stimulus now led the swapped stimulus to become dominant. This is clear evidence that the eyes play an important role in rivalry. Bhardwaj et al. (2008) found that conventional rivalry could involve rivalry between the eyes or between images or both, whereas the swapping method is more likely to induce a competition between patterns.

In a fMRI-study Haynes et al. (2005) observed a strong correlation of a specific eye being perceptually suppressed and strongly decreased activities in LGN-regions of that specific eye. The authors infered the LGN to be „the earliest stage of visual processing that reflects eye-specific dominance and suppression.“ This correlation between the percept and neuronal activity in early stages of the visual system could not be confirmed in a single-unit study with awake behaving monkeys (Leopold and Logothetis, 1996) – these investigators found a high correlation between a percept and neuronal activity in V4 and MT.

In a further study carried out by Sheinberg and Logothetis (1997) most of the inferotemporal neurons showed changes of activity according to the perceived stimuli during rivalry trials. While these results fail to support interocular competition theories, these investigators concluded rivalry to be a *competition between pattern representations*, well resolved beyond information processing in inferior temporal areas, a finding, which was confirmed by Kovács et al. (1996).

Bottom-up processing and attention

Attention is not simply monitoring or focussing an object. Rather it might be driven in a bottom-up manner by objects one perceives, in the literature often referred to as *exogenous or involuntary attention,* or in a top-down manner (see below). There are several studies which focus on the relationship between binocular rivalry and exogenous or involuntary attention.

The purpose of the Mitchell's et al. study (2004) was to find out if *object-based attention*, driven involuntarly, could influence rivalry. The investigators used two superimposed and oppositely rotating dots on transparent surfaces as rival stimuli and cued one of the dot sets to focus (bottom-up driven) attention on this certain stimulus. Mitchell et al. (2004) report that observers usually perceived the previously cued direction as dominant and state that there is undouptedly an attentional influence on binocular rivalry and that their findings also establish a connenction between rivalry and object-based attention. Khoe et al. (2008) confirmed Mitchell's et al. (2004) result by adopting the „rotating dots" paradigm used in the Mitchell's et al. (2004) study and, by using ERP's which allows precise timing, could show that the cueing effect within a time window 160 – 220 ms (N1 component of ERP) and 250 – 300 ms (P2 component of ERP) was larger under rivalry conditions than under monocular viewing.

Meng and Tong (2004) were the first researchers who compared the role of attention over different forms of bistable perception. They discovered that while other forms of bistable figures like ambiguous figures, which can be perceived in more than one way, are much more strongly influenced by selective top-down attention, binocular rivalry is considered to be more stimulus- (bottom-up-)driven and might be influenced by selective attention only to a small amount.

Top-down approach: The majority of research on top-down processing in rivalry focuses on high-level representations which influence rivalry in a retrograde fashion. In a recent work Sobel and Blake (2001) conducted an imaginative experiment: a quartet of circles with implied shading in the upper or lower half served as stimuli. It is a well known optical illusion that a shade's position causes the visual system to infer a hump or a dent even from a 2-D drawing. In the experiment one eye viewed an array of circles (perceived as humps or dents) while the other eye viewed an array of the same circles in the same position (also perceived as humps or dents) with the exception of one which was replaced by a radial grating. This grating was incompatible to the hump or dent of the other eye and thus rival. Sobel and his colleague found a

clear enhancement of predominance for the hump (or dent) embedded in its fitting context.

Yu and Blake (1992) wanted to find out if configural properties of a stimulus can dominate over random dot patterns equated in their physical appearance. For these purposes they presented their participants with a series of recognizable stimuli (the authors interpret „recognizable“ as an object which can „unambigously segregated from its background“). They chose a face and a random dot pattern, created out of the face image, versus a neutral stimulus equated for spatial frequency, contrast, and luminance as dissimilar stimuli. Increased predominance of the face vs. a neutral stimulus over the face's random dot pattern vs. the same neutral stimulus was shown in this study. In a second experiment Yu and Blake (1992) wanted to test whether it was recognizability per se which led the target stimulus to dominance. Therefore, they presented their participants with a camouflaged picture (a drawing of a Dalmatian dog) and a scrambled picture of the same dog's drawing. Again the whole object increased the predominance even before participants were aware of the content of this camouflaged picture, thus showing that the mechanisms underlying binocular rivalry at least in part are sensitive to configural properties of a stimulus.

If one accepts this inference the logical question is what might help top-down processes to influence binocular rivalry? There are several studies which point to attention as a powerful variable.

Top-down processing and attention

Endogenous or voluntary attention is defined as one's ability to focus the attention actively corresponding to one's current goals, intentions, strategies, and thus is carried out in a top-down manner (for a review see Gilbert and Sigman, 2007).

In their widely noted study Ooi and He (1999) investigated modulational mechanisms of attention on perceptual rivalry. The authors modified the classical Cheshire Cat Paradigm (Grindley, Townsend, 1965; Duensing, Miller B, 1979): motion of a certain velocity (20^0 visual angle/sec) in one of the two

parts of the binocular fields can trigger suppression to the corresponding part of the other. Ooi and He (1999) designed an apparant motion perturbation: they showed that a part of the monocular image is suppressed when an apparant motion stimulus is presented to the contralateral eye which sees a blank field. The authors could show that voluntary attention to a dominant stimulus helps this stimulus to maintain dominance and weakens the apparant motion effect. These results show that rivalry might also be influenced by *space-based, voluntary attention*.

Sasaki and Gyoba (2002) also used a perturbation paradigm similar to that of Ooi and He (1999) and instructed their participants to attend to a certain stimulus. Sasaki et al. (2002) report a modulation of interocular suppression when participants attended specific features.

Chong and Blake (2005) compared the strength of exogenous and endogenous attention on binocular rivalry processing within one study by focussing on the onset of rivalry. They found evidence for both forms of attention to influence the initial dominance.

Paffen, Alais, and Verstraten (2006) observed a clear effect of endogenous attention on the velocity of alternations: the more difficult it was for participants to attend during rivalry the more alternations slowed down, but the authors also point out that rivalry never came to a standstill.

If voluntary attention clearly affects the time processing of alternations, how does top-down attentional processing act on the dominance and suppression phases of a certain stimulus? A recent study turned to this point. Hancock and Andrews (2007) could replicate the positive effects of both exogenous and endogenous attention on binocular rivalry. The investigators presented their participants with two orthogonal gratings with same spatial frequency (the lines within a grating were equidistant) but different contrast. A letter cue preceded rivalry trials requesting participants to attend and observe changes in orientation. Hancock and Andrews (2007) found a clear effect on the phases of rivalry: Voluntary attention had no effect on the mean dominance durations of the attended stimulus, but decreased the mean dominance of the „neutral“ (unattented) stimulus.

Thus, some studies indicate that top-down attention influences rivalry. In these studies participants are to attend to a certain stimulus. Therefore, only one of the functions of attention had been tested on rivalry, namely its perceptual selection function. This leaves open the question if other functions of attention can also influence binocular rivalry.

1.4 The present experiments

The present experiments investigate the influence of top-down attentional processes on binocular rivalry. As mentioned above some studies revealed a top-down attention effect on binocular rivalry by instructing participants “to pay attention” to a certain stimulus. The present thesis focuses on the question whether other dimensions of attention influence rivalry, e.g. selection for action, or the role of attention in learning and recognition. Thus, two experiments were carried out, an action intention experiment (experiment 1), and a learning and recognition experiment (experiment 2).

Action intention experiment (experiment 1): Maruya et al. (2007) discovered that a concurrent action influences binocular rivalry when action and stimulus move in the same direction. I hypothezised that an intention to act also affects rivalry. Tool images serve as target stimuli in the rivalry experiment and signal an action to be carried out after each trial. Influences on the initial stimulus to be perceived and frequencies of dominances and suppressions are investigated.

Learning experiment (experiment 2): In binocular rivalry highly overlearnt objects like faces or dogs predominate patterns equated in physical appearance (Yu et al., 1992). The ability to identify an object improves with training (see Sigman and Gilbert, 2000). I speculated whether a recently learnt stimulus influences rivalry. The learning experiment investigates if a previously learnt meaningful stimulus derives benefit from top-down attention. I hypothesized that the previously learnt stimulus is perceived first at rivalry onset, and is perceived more often than non-target stimuli.

2 Experiment 1: Action-Intention and Binocular Rivalry

2.1 Interactions between action and perception

Patients with lesions in their dorsal streams of the visual pathway (superior regions of the posterior parietal cortex) may be unable to use visual information to direct a grasp or a movement to a certain object (Perenin, Vighetto, 1988). This indicates a strong interaction between vision and motor behavior. The aim of the first experiment was to make use of this interaction to investigate the influence of action planning on binocular rivalry via top-down attentional processing.

Since the original proposal of two visual systems processing perceptual and action information (Goodale, Milner, 1992; see chapter 1.1) many studies have been carried out to find out how these systems interact. Using the **P**ositron**E**mission**T**omography imaging method, Martin et al. (2000) discovered that the semantic representation of an object is implemented in a distributed network, which connects sensory and motor systems in the brain. Using **f**unctional **M**agnet **R**esonance **I**maging, Chao et al. (2000) confirmed these findings: the recognition of objects, such as tools, depends on activity in ventral and dorsal parts of the visual system. Even when their participants just named the tools, the authors could observe an activation of the left ventral premotor cortex.

But how do the two systems work together and, are these influences uni- or bidirectional? In several psychophysical experiments Stoet and Hommel (2002) showed that feature integration in perception affects action planning. Tucker and Ellis (1998) found was that perceived objects boost action components according to their affordance. Affordances are intrinsic to the objects' representation and may be understood as stimulus properties such as location, size, orientation, or shape, which generate automatic response properties.

The influence of action on perception was also studied: If participants plan actions they draw attention to particular features of a visual target, these features are highlighted by attentional processes (Pavese and Buxbaum, 2002). If, in contrast, participants show different types of action, different parts in the visual scene are highlighted: pointing enhances spatial selection while grasping highlight object-based features, via spatial and object-based attention respectively (Linnell et al., 2005). Hecht et al. (2001) found an action-perception transfer by having participants learn a motor movement without visual feedback, a finding which was confirmed by Casile et al. (2006).

But do action representations influence visual object recognition? This is the question addressed by Helbig, Graf and Kiefer (2006) who found that the answer is yes, but there are limitations to that: Action representations may influence visual object recognition, but only if the objects are associated with a similar action, in other words, if there is a congruent relationship. Furthermore the transfer only takes place for real objects or objects presented by pictures, not by words.

A mutual influence of perception and action is evident. To my knowledge only one study applied the perception-action connection to a binocular rivalry experiment (Maruya, Yang, and Blake, 2007). The authors observed an influence of actions on rivalry. While Maruya et al. (2007) implemented concurrent *actions* in their rivalry experiments, the effect of the intention to act without any concurrent actions remains unknown.

Thus, I speculated that the representation of an action intention may influence binocular rivalry. I hypothezised that an action intention will help the target stimulus to become dominant at rivalry onset, and do so more often compared to the non-target stimulus.

To investigate further attentional effects of action intentions the third aim was to test whether the (perceptual) phase durations of the perceived target stimulus will prolong. To do so, I adopted a method first introduced by Mamassian and Goutcher (2005), in which participants had to report their current percept every two seconds. To activate the action intention I additionally presented the participants with an acoustic cue to focus their attention on the functional part

of a given tool. If action intentions influence rivalry the image consciously perceived after the acoustic cue should be the target stimulus.

2.2 Experiment 1 (Action intention experiment)

2.2.1 Methods

Participants

Twentytwo participants (age: 22 – 52 years; mean: 30,9 years; 13 female) took part in the experiment. All participants had normal or corrected-to-normal vision and no restrictions in hearing. All participants were naive to the purposes and hypotheses of the experiment.

Task

In the rivalry experiment participants had to report their current percepts whenever a prompt occured every two seconds. For the experimental group, an additional tone served as a cue to focus attention on the functional part of the tool shown. When they perceived an intact tool while being presented with the acoustic cue, participants were to pick an identical tool out from a toolbox after the trial. In contrast, the control group was told they participate in a concentration experiment which tests their ability to ignore the acoustic cue.

Apparatus

The experiment were run on a 50-60 Hz Miro C2096 19`` Color Monitor. Presentation of both visual and auditory stimuli was controlled by Presentation® (Neurobehavioral Systems, Albany, CA), running on a Microsoft® XP professional operated personal computer.

Auditory stimuli were presented via two small loudspeakers (SONY ACTIVE SPEAKER SYSTEM SRS-A5), which were placed symmetrically to the left and right side of the monitor in front of the participant. Auditory output was controlled by a Realtek AC 97 Audio soundchip.

For reporting their perceptions, participants had to use a modified mouse with their feet (figure 2).

A Reichert 338 814 Microscope was rebuilt to serve as a stereoscope. Participants could adjust the height and angles of the stereoscope. The metal base of the stereoscope was covered by a black cloth. The desk and the wall

next to the participants were covered by black cardboard to reduce light reflections to a minimum.

Figure 2: Footpedals of the modified mouse.

Stimuli

Visual stimuli:

Visual stimuli of the action intention experiment (objects like hammer, screwdriver, pairs of pliers) come from clip-arts toolboxes and were modified by Adobe Photoshop®, Adobe InDesign®, CorelDraw®, and Macromedia Freehand®. To avoid differences in physical appearance, all stimuli had the same line thickness. Red and green background colors had the same brightness and luminance. All stimuli were tested in pretests.

Left and right eye visual stimuli consisted of a black square filled with a grey pattern. Squares and patterns were identical for every stimulus to help participants fuse a presented pair. To cause rivalry a hexagon was centered in the square, which was filled with a green or red background. Thus, each stimulus pair consisted of a green background presented to the left eye, and a red background presented to the right eye, or vice versa. Further, within the centered hexagon rivalrous stimuli were placed. Neutral stimuli were vertical or horizontal gratings, or were meaningful objects (such as a moon, flower, sun, or a star) that were neutral with respect to the purposes of the experiment. The target stimuli consisted of pictures of tools such as hammer, screw driver,

wrench, and pliers. Half of the tool stimuli was functionally intact while the other half was graphically modified so that they appeared broken (figure 3).

Auditory stimuli:

Two different tones were used.

* prompt: Participants were to report their current percepts whenever a 500Hz-prompt was presented at 48 dB loudness every two seconds during a trial.

* acoustic cue: A different tone (Windows© XP Professional, 2002, notify.wav), randomly presented at 48 dB and at most four times per trial, served as a cue to focus attention on tool images in the experimental group.

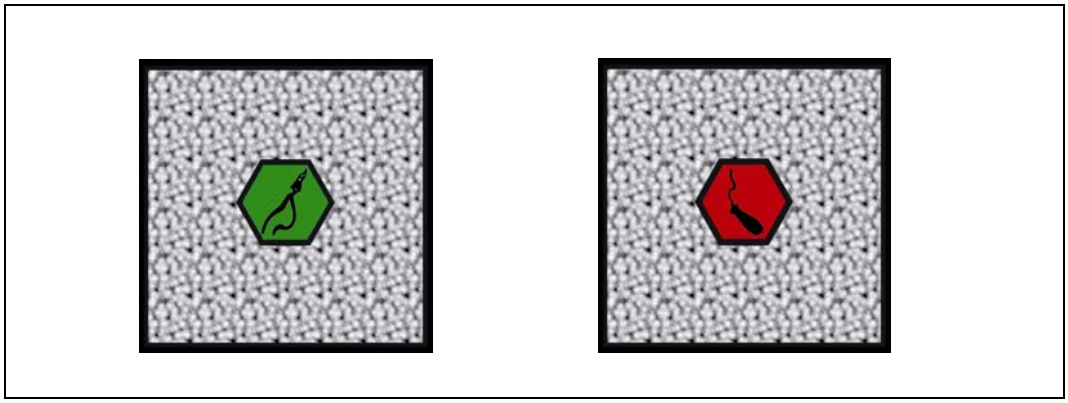

Figure 3: Two examples of the broken tool stimuli.

Pretests

By pretests, the goals were to test the stereoscope, to make sure that the auditory stimuli do not induce a startle reaction, to test the visual stimuli, and to check the durations of the intervals, during which participants had to report what image they perceive. Eleven participants (mean age 29,5; range from 20 to 49) took part. All of them had normal or corrected-to-normal vision, no participant had any restrictions in hearing. Participants gave feedback on the functioning of the stereoscope. During the pretests the colored backgrounds were adjusted to each other regarding contrast and brightness, because otherwise the image with the higher brightness or contrast would have been dominant, that is, this image would have been perceived most of the time.

Therefore in the pretests participants had to report the switchings. Only those pairings were accepted for the target set in which the two stimuli had been perceived with nearly the same frequencies (the range between a 46% : 54% rate was accepted). Participants judged the stimuli`s quality twice per pair to avoid eye dominance. Stimuli which had been presented to the left eye first, were presented to the right eye in the second trial and vice versa. One trial lasted 50 seconds.
In the pretests 26 of the initial 50 stimuli met the frequency-criterion mentioned above, 21 of them were included into the experiment.

Design
For the experimental group the experiment was subdivided into a practice and a rivalry part. The control group participated in the rivalry part only. For both groups written instructions were presented on the screen.

Experimental group:
Task 1 – Practice on tools. Before using the stereoscope, participants underwent practice on tools. Participants were presented with four wooden boards of 30 cm x 30 cm. In two of these boards 25 holes (5 rows à 5 holes) had been stamped. The task was to tack in as many nails as possible into the holes within 30 seconds. Before doing so participants had to choose the right tool in proper size. For the other board the task was to twist in as many screws as possible in 30 seconds. Again, the best fitting tool had to be chosen. For boards 3 and 4 the task was reversed: either the nails had to be pulled out with the proper wrench, or screws had to be unscrewed, within 30 seconds each task.

Task 2 – Foot pedals. Immediately after practising participants learnt to report their percepts on a modified mouse (see figure 2, section „apparatus“) by using their left or right foot. Altogether 15 images were presented.

Task 3 – Introduction of the acoustic cue.

Task: Participants were presented with visual stimuli consisting of neutral and target (tool) images. An acoustic cue was introduced. When presented with the acoustic cue, participants had to report whether the shown tool was broken or intact.

Stimuli: Neutral stimuli showed horizontal or vertical gratings, and stylised suns, flowers, stars. Target stimuli showed tools like hammer, screwdriver, pairs of pliers. Broken tools showed tools with damaged functional parts. Neutral images showed horizontal or vertical gratings, and stylised suns, flowers, stars.

Timing of the acoustic cue: 1000 ms before a target image (intact / broken tool) was presented, the acoustic cue (500 ms duration) appeared. Images only disappeared from screen after participants had pressed one of the answer keys. After 3000 ms the next stimulus (neutral image or acoustic cue) was presented.

Task 4 – Introduction of the stereoscope. Participants had an introduction of how to use the stereoscope and learnt to report their percepts every two seconds at the request of an auditory stimulus (= prompt), which was presented every two seconds.

Practice task. In the final introductory task participants had to practice the tasks: participants were presented with image pairs on the stereoscope and were to report their current percepts due to the prompts every two seconds. Further, participants were to check whether an intact tool was presented while the acoustic cue appeared. If they had perceived an intact tool they were required to pick this tool out of a toolbox after the trial.

Stimuli: Visual and auditory stimuli were the same as described above.

Control group:

The control group did not receive any practical training, but underwent the same excercise at the stereoscope as the experimental group, and thus was familiarized with both visual and auditory stimuli.

Trial events of the rivalry experiment

The main experiment consisted of 19 trials, with a duration of 42 – 52 seconds each. Stimulus pairs consisted of neutral-neutral pairs (5), neutral-broken tool pairs (6), neutral-intact tool pairs (6), broken tool-intact tool pairs (2) and were randomly presented. Trial starts were indicated by the word „ready“ in white. As soon as participants pressed the enter key the trial started and a visual stimulus pair was shown immediately. The first prompt appeared 1000 ms after trial onset, and re-appeared every two seconds. The additional acoustic cue appeared randomly, at most four times per trial. Time between a prompt and a following acoustic cue was 1000 ms. Time between an acoustic cue and the following prompt was 700 ms. Four trials were presented with prompts only. Figure 4 shows a typical trial.

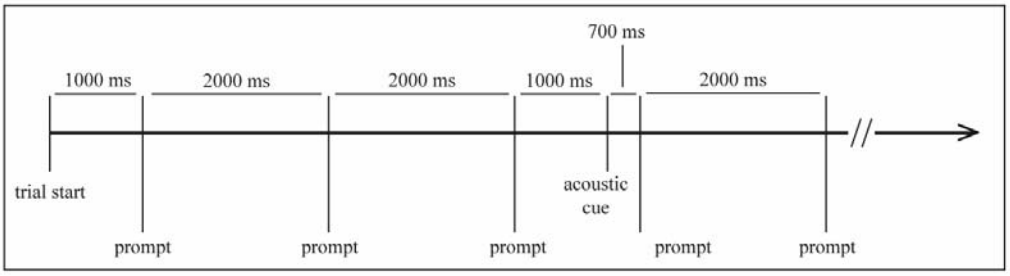

Figure 4:Timing of trial events

Procedure

Before starting the experiment, participants were asked for impairments in vision or hearing. Some information was given about binocular vision and the use of stereoscopes. All persons participated voluntarily and did not receive a fee.

All trials were recorded in logfiles. Introduction tasks were also recorded and later served as control whether the person had understood the instruction, answered properly and within the proper time-window, and to discard outliers due to anticipation. The whole experiment lasted approximately 40 minutes.

Data analyses

Recorded logfiles provided the raw data of event types (sort of stimulus presented), answers given by participants, exact timing of all events. The logfiles built the bases for Excel tables in which the absolute frequencies of each stimulus seen in one trial was calculated, the percentages of perceived images, the absolute frequencies and percentages of errors made (note: missed answers or outliers concerning the timing were considered to be errors and omitted from further analysis). If participants missed more than 20% of answers the trial in question was completely discarded from analysis. To complete the tables I also determined phase durations (see below) and alternations after the acoustic cue (see below).

Absolute frequencies of initially perceived stimuli (target, non-target) of all trials were calculated and tested. An initially perceived stimulus is defined as the stimulus participants reported to have seen after the first prompt.

Absolute frequencies of target and non-target stimulus percepts respectively were calculated and tested. Logfiles had been programmed such that a left or right mouseclick made it easy to assign what stimulus the participant had perceived at a certain time.

Switching rates were determined by counting the number of alternations of the two percepts per trial, and tested.

A phase duration is defined as the time a current percept is constantly seen. In my experiments this value is limited by the prompts. As the prompt requested report every two seconds, the value of a phase duration is calculated by simply adding all two-seconds-intervals during which participants had consecutively perceived a certain stimulus. For this reason one finds a 2-seconds-phase (= *phase 1*), a 4-seconds-phase (= *phase 2*), a 6-seconds-phase (= *phase 3*) and so on. For each stimulus in a trial the different phase durations were identified and frequencies were calculated. Normally these phases show a left-skewed

distribution. Thus, before starting further phases analyses, data were graphically checked whether they were left skewed or not.
Subsequent phase duration analyses addressed each phase duration separately within both experimental and control group respectively and comparisons between these two groups.

Alternations after acoustic cue: The acoustic cue served as a cue to focus a participant's attention on the target stimulus. Thus, the perceived stimuli right before and after the cue were analysed.

Four possible successions were analysed:

* neutral percept -> acoustic cue -> neutral percept (neutral-neutral alternation)
* neutral percept -> acoustic cue -> target percept (neutral-target alternation)
* target percept -> acoustic cue -> neutral percept (target-neutral alternation)
* target percept -> acoustic cue -> target percept (target-target alternation).

If one compares neutral-neutral alternations with neutral-target alternations one should find differences between the experimental and control group. One should also expect differences for the two groups when comparing target-target alternations with target-neutral alternations.
Thus, two further analyses were done for both experimental and control group:

* neutral-neutral alternations vs neutral-target alternations
* target-target alternations vs target-neutral alternations.

2.3 Results

Eleven out of 391 trials had to be discarded from analysis for too many missed answers (9) and for containing answers to only one stimulus (2).

Initial target image / non-target image percepts

Initially perceived images.

Action planning had an influence on the initially perceived target stimulus at rivalry onset. Participants of the experimental condition perceived the tool (target) stimuli more often than the non-target stimulus [Mann-Whitney U = 4294; $p < 0.0001$], while in control group it was the non-target stimulus [Mann-Whitney U = 6250; $p = 0.0016$] which was perceived more often. Compared to the control group, in experimental group the target stimulus was more often the first stimulus to be perceived [Mann-Whitney U 5200; $p < 0.0001$].

Absolute frequencies of target / non-target percepts

Absolute frequencies of target vs non-target percepts.

The experimental group perceived the target stimulus more often than the non-target stimulus [$t = 2.422$; $p = 0.0163$]. In the control group this finding reversed: here participants perceived the non-target more often [$t = 2.605$; $p = 0.0098$]. Participants of the experimental condition perceived the target stimulus more often than the control group did [$t = 3.202$; $p = 0.0016$]. Regarding non-target percepts there was a small difference such as the non-targets seemed to be perceived more often by control participants, but the result was not statistically significant [$t = 1.412$; $p = 0.1593$].

Absolute frequencies of percepts of intact and broken tools.

Participants of the experimental group perceived intact tool stimuli more often than broken tools stimuli [$t = 2.866$; $p = 0.0069$]. Within the control group one could find no difference [$t = 0.5625$; $p = 0.5780$]. Comparing experimental and control group, no differences could be shown in absolute frequencies of

percepts of intact tools [t = 1.399; p = 0.1713] and absolute frequencies of percepts of broken tools [t = 0.9877; p = 0.3305].

Graphs of absolute frequencies of target and non-target percepts per every two-seconds-phase of all trials.

The figures below show the absolute frequencies of target stimulus and non-target stimulus percepts that had been reported after the feedback tone, which had appeared every two seconds. Frequencies contain data of all trials. Figure 5 shows the data of the experimental group, while figure 6 shows the data of the control group. Decreases of the curves at the end of the trials are due to the fact that the acoustic cue was given one to four times at most per trial. The more acoustic cues were given the longer the trial lasted. While numbers of trials with one, two, three, and four acoustic cues were identical, long lasting trials were less frequent.

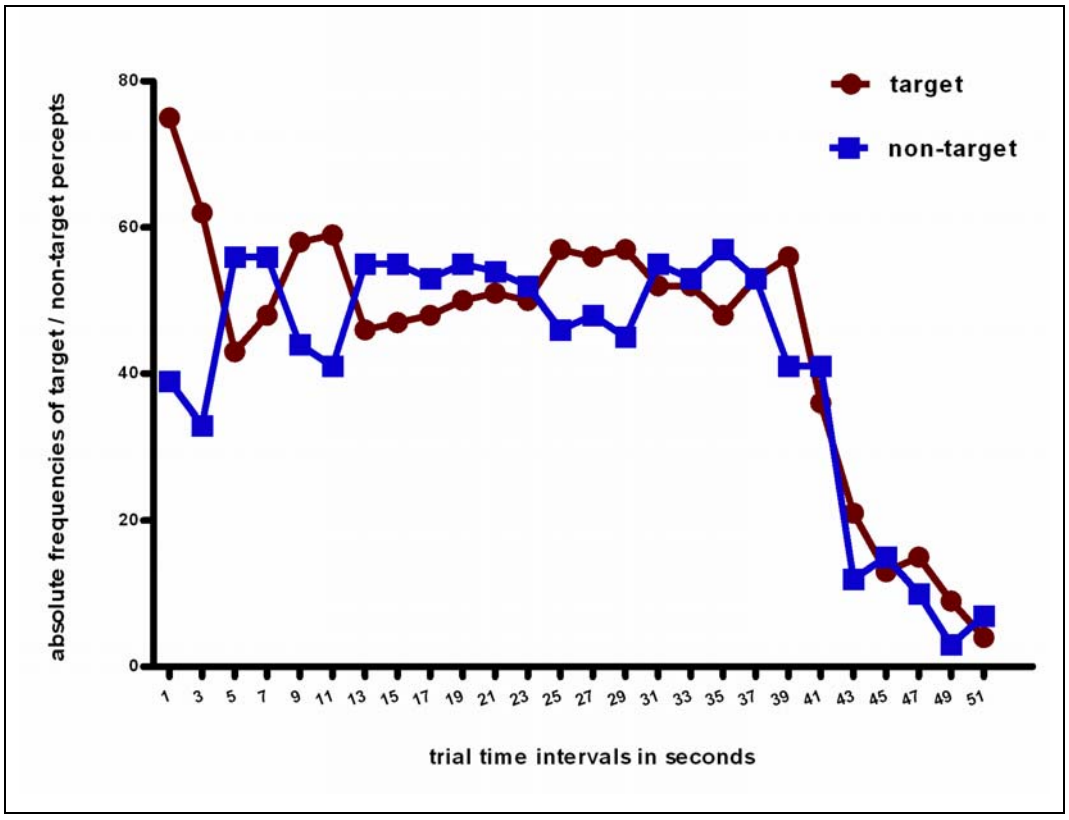

Figure 5: Action intention experiment – experimental group: absolute frequencies of target stimulus and non-target stimulus reports of all trials. Frequencies of percepts as reported every two seconds are shown.

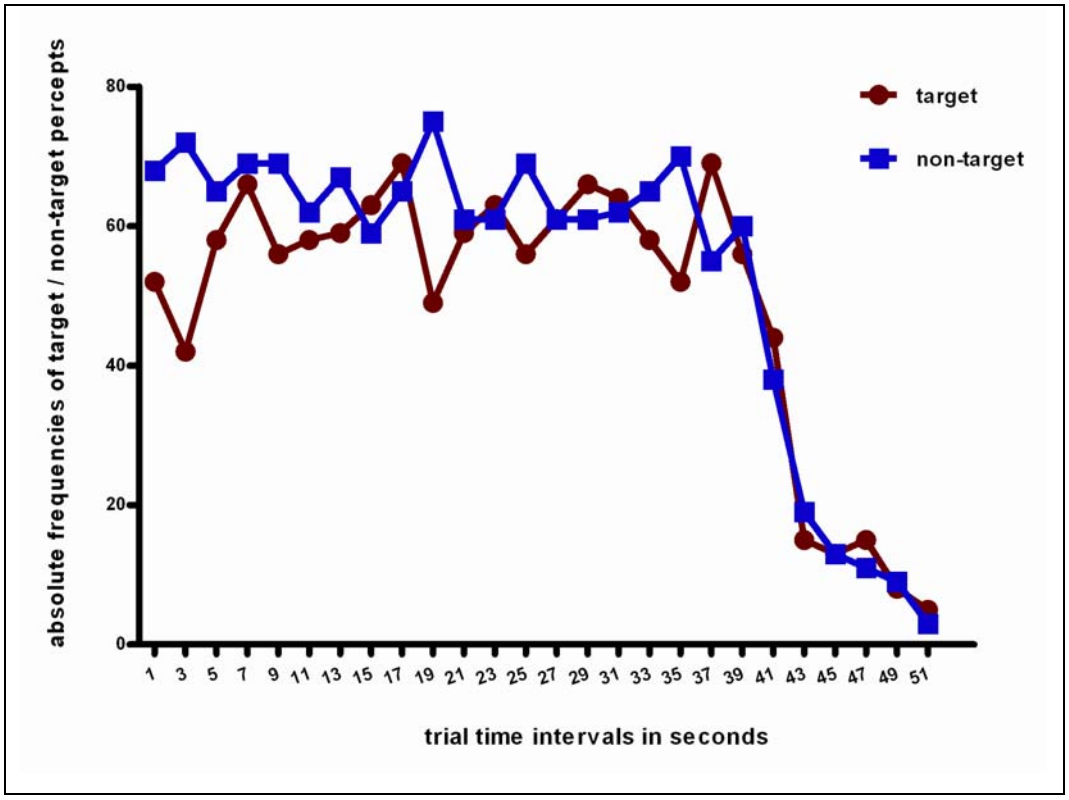

Figure 6: Action intention experiment – control group: absolute frequencies of target stimulus and non-target stimulus reports of all trials. Frequencies of percepts as reported every two seconds are shown.

Switching rates

Switching rates of target and non-target trials.

In both experimental and control group switching rates were higher in non-target trials [experimental: t = 2.322; p = 0.0215 – control: t = 3.248; p = 0.0014]. In comparison switching rates of the two groups did not differ significantly, neither in target trials [t = 0.8374; p = 0.4032] nor in non-target trials [t = 0.9541; p = 0.3424].

Switching rates of neutral trials with and without acoustic cue.

It turned out that the acoustic cue per se had an effect on the switching rates in those trials in which no targets had been presented. In neutral trials with acoustic cue compared to those without acoustic cue the switching rates slowed down. This effect was significant in experimental group [t = 2.449; p = 0.0180] as well as in control group [t = 2.465; p = 0.0170].

Comparing neutral trials with acoustic cue in the two groups, no effect could be shown [t = 0.2797; p = 0.7805]. The same could be shown for neutral trials, in which no acoustic cues had been presented: again, no difference between experimental and control group turned out [t = 0.8287; p = 0.4116].

Switching rates of target trials with vs without acoustic cue.

Comparing target trials in which acoustic cues had been presented, and those without any acoustic cue, there was no significant result in control group [t = 1.109; p = 0.2699], but the experimental group showed an effect: in target trials without the acoustic cue switching rates were higher. These differences failed to reach significance when means are compared [t = 0.7770; p = 0.4391], but the two variances differed significantly [F = 2.370; p = 0.0098].

Phase durations

Skewness of phase durations. In binocular rivalry experiments dominance phases normally follow a left skewed distribution. Therefore phase durations of the following conditions were graphically analysed: phase durations of target percepts and non-target percepts in experimental group (figure 7) and phase durations of target percepts and non-target percepts in control group (figure 8). All phase durations are left skewed. Viewing times for the different phases were as follows: phase 1 at most 2 seconds, phase 2 at most 4 seconds, phase 3 at most 6 seconds, phase 4 at most 8 seconds, phase 5 at most 10 seconds, phase 6 at most 12 seconds.

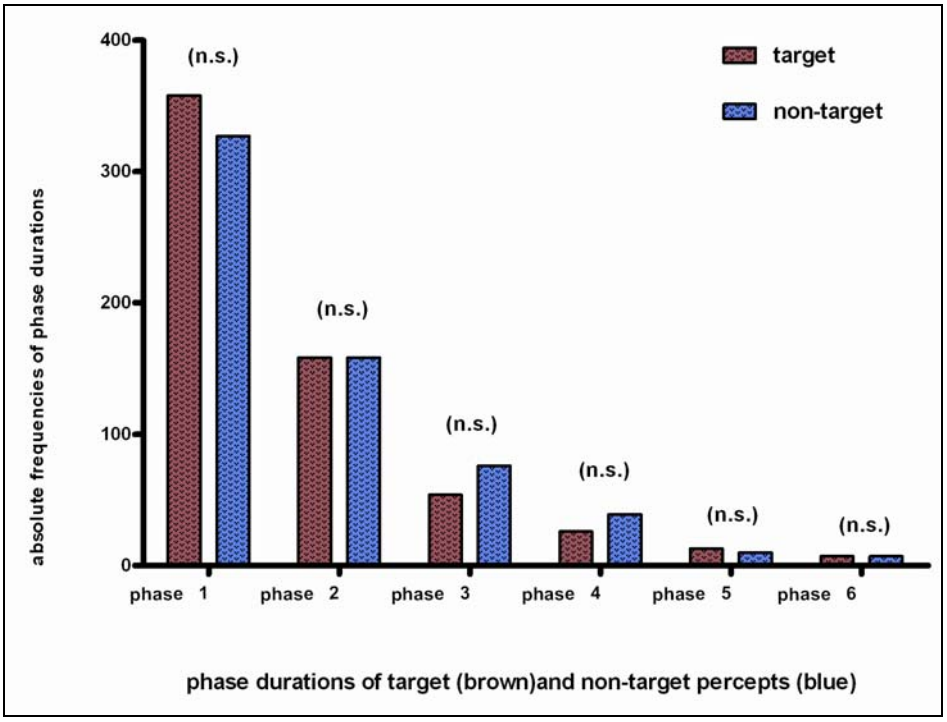

Figure 7: Action intention experiment – experimental group: phase durations of target (brown) and non-target (blue) percepts. Phase 1 includes viewing times of at the most two seconds, phase 2 four seconds, phase 3 six seconds, phase 4 eight seconds, phase 5 ten seconds and phase 6 twelve seconds.

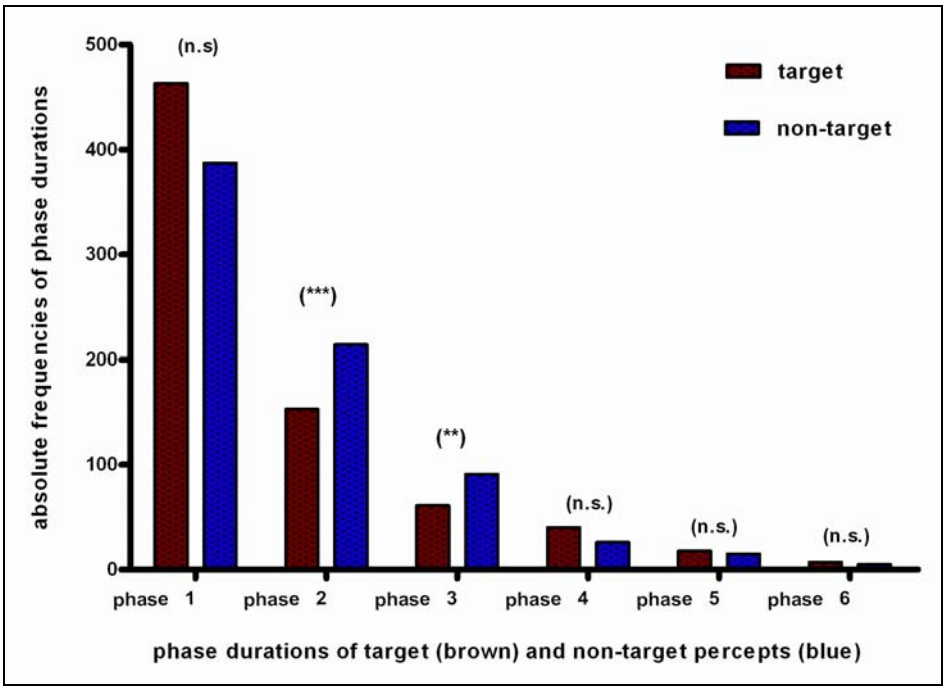

Figure 8: Action intention experiment – control group: phase durations of target (brown) and non-target (blue) percepts. Phase 1 includes viewing times of at the most two seconds, phase 2 four seconds, phase 3 six seconds, phase 4 eight seconds, phase 5 ten seconds and phase 6 twelve seconds.

Phase durations of target and non-target percepts in experimental and control group.

Phase 1 target vs non-target percepts did not differ significantly in experimental group [Mann-Whitney U = 5902; p = 0.4407]. This was also the case in control group [Mann-Whitney U = 6869; p = 0.0622].

For *phase 2* the experimental group showed no difference in frequencies of target percepts vs non-target percepts [Mann-Whitney U = 6217; p = 0.9075]. But for the control group the result changed. Here I found an extremely significant effect: the control group perceived more phases of the non-target stimulus [Mann-Whitney U = 5500; p < 0.0001].

In experimental group no difference could be shown in *phase 3* [Mann-Whitney U = 5449; p = 0.0560]. In contrast, in control group a highly significant difference was found: as in phase 2, the control group perceived more non-target stimuli.

Both experimental and control group produced no differences in perceiving *phases 4* target vs non-target stimuli [experimental: Mann-Whitney U = 5757; p = 0.1568 – control: Mann-Whitney U = 7308; p = 0.2213].

No significant results were found for *phase 5* target vs non-target percepts [experimental: Mann-Whitney U = 6155; p = 0.6413 – control: Mann-Whitney U = 7695; p = 0.4675].

Frequencies of *phase 6* target vs non-target percepts were identical in experimental and control group and also produced no significance [experimental: Mann-Whitney U = 6100; p = 0.5311 – control: Mann-Whitney U = 7565; p = 0.6720].

Phase durations of non-target percepts in experimental vs control group.

For *phase 1*, no difference in frequencies of non-target percepts between experimental and control group could be observed [Mann-Whitney U = 6750; p = 0.5602].

For *phase 2* frequencies of non-target percepts were higher in control group [Mann-Whitney U = 5974; p = 0.0351], which is considered to be significant.

Frequencies of *phase 3* durations did not differ significantly between the two groups [Mann-Whitney U = 6747; p = 5252].

The same result is shown in *phase 4* duration: no difference could be found out between experimental and control group [Mann-Whitney U = 6573; p = 0.2727].

Phase 5 analysis produced no difference in frequencies of non-target percepts between experimental and control group [Mann-Whitney U = 6897; p = 0.5666].

Absolute frequencies of *phase 6* in experimental vs control group were equal [Mann-Whitney U = 6921; p = 0.9358].

All results of phase duration of non-target percepts are shown in table 1.

Table 1: Action intention experiment: non-target phase durations in experimental vs control group

non-target phases	**experimental vs control group**
phase 1	n.s.
phase 2	(*) experimental < control
phase 3	n.s.
phase 4	n.s.
phase 5	n.s.
phase 6	n.s.

Phase durations of target percepts in experimental vs control group.

Phase 1 target percepts did not differ in experimental and control group [Mann-Whitney U = 6248; p = 0.1247].

Participants of the experimental group perceived more *phase 2* target phases than participants in control group – this difference is statistically significant [Mann-Whitney U = 5971; 0.0326].

Target percepts of *phase 3*-duration was equally frequent in both groups [Mann-Whitney U = 7053; p = 0.9956].

The same result (no significance) was found for *phase 4* frequencies [Mann-Whitney U = 6653; p = 0.3680] and *phase 5* frequencies [Mann-Whitney U = 6813; p = 0.4264].

For *phase 6* frequencies there seemed to be a difference in favor of the experimental group. But this difference failed to be statistically significant [Mann-Whitney U = 6621; p = 0.2559].

Results of all target percept phases are shown in table 2.

Table 2: Action intention experiment: target phase durations in experimental vs control group

target phases	experimental vs control group
phase 1	n.s.
phase 2	(*) experimental > control
phase 3	n.s.
phase 4	n.s.
phase 5	n.s.
phase 6	n.s.

Alternations after acoustic cue

Perceived stimuli before and after the acoustic cue have been analysed. Based on this consideration four conditions are focused: neutral-neutral, neutral-target, target-target, target-neutral, table 3 sums up all results.

Neutral-neutral alternations after acoustic cue.
In this condition more alternations were registered in control group. The comparisons of the two groups' means was not statistically significant [t = 1.123; p = 0.2763].

Neutral-target alternations after acoustic cue.
The probability of perceiving a target stimulus after participants had perceived a neutral one was identical for both groups [t = 0.8402; p = 0.4118].

Target-target alternations after acoustic cue.
For both experimental and control group absolute frequencies of alternations from target percept to target percept were identical and thus not statistically significant [t = 0.9715; p = 0.3442].

Target-neutral alternations after acoustic cue.
The control group showed more alternations to the neutral percept after the acoustic cue. This result turned out to be extremely significant [t = 4.700; p = 0.0002].

Table 3: Action intention experiment: alternations after acoustic cue in experimental vs control group

alternations	experimental vs control group
neutral-neutral	n.s.
neutral-target	n.s.
target-target	n.s.
target-neutral	(***) experimental < control

In the following, two further results are shown: comparison of neutral-neutral alternations with neutral-target alternations and target-target alternations with target-neutral alternations. The results are summarized in table 4.

Neutral-neutral vs neutral-target alternations after acoustic cue.

After the perception of the neutral stimulus more alternations to the target had been registered in experimental group. This result is significant [t = 2.828; p = 0.0111]. In control group no difference could be found [t =0.3721; p = 0.7142].

Target-target vs target-neutral alternations after acoustic cue.

After the perception of the target stimulus the experimental group again perceived the target stimulus more often than the neutral one [t = 2.694; p = 0.0148; significant]. In control group no difference was found [t = 1.140; p = 0.2694; n.s].

Table 4: Action intention experiment: comparison of neutral-neutral alternations vs neutral-target alternations; comparison of target-target alternations vs target-neutral alternations in experimental and control group respectively.

comparison of alternations	experimental group	control group
neutral-neutral vs neutral-target	(*) neutral-neutral < neutral-target	n.s.
target-target vs target-neutral	(**) target-target > target-neutral	n.s.

2.4 Discussion

Effects of an action intention on binocular rivalry have been shown.

Initial percept

Clearly affected was the initial percept at rivalry onset: when rivalry started, the experimental group perceived the target stimulus more often than the neutral one. With no doubt this is due to an endogenous attentional top-down processing forced by intended actions, for there had been no external cue. Attention is known for its main purpose to select a certain stimulus among others and its ability to influence many aspects of vision (see Pashler, 1999 for an overview). Several studies confirmed that different forms of attention influence binocular rivalry. Chong and Blake (2006) recently showed that endogenous attention helped the target stimulus to become dominant first. Participants had to track a feature to focus endogenous attention to a changing orientation of the target, which was first presented dioptically (one stimulus seen by both eyes) before rivalry sessions began. In my experiment endogenous attention had been focussed on certain features by inducing an action intention, thus, participants were forced to focus voluntary attention on the target's feature (functional part of the intact tool). Concerning the effect of endogenous attention my data complement those of Chong and Blake (2006).

Recently Carter and Cavanagh (2007) studied the conditions underlying the preference of the initial stimulus („onset rivalry"). They intermittently presented a rival stimulus (1 sec; at 10 sec intervals to induce onsets of rivalry) in the fovea and in other locations peripherically and found a strong location bias. Due to their experimental set regions of monocular dominance or adaptation to a predictable trajectory could be excluded. The bias of the target's location specifity remained even when the experimenters moved the target smoothly in the visual periphery. Interestingly, the local biases turned out to be stable for at least 2 weeks. If such a bias had occurred in target percepts in my experimental group, one would expect to find this bias also in control participants, which definitely was not the case. Instead, in the control group the initial stimuli mainly perceived were the non-targets. Had these percepts been biased by the location specifity found in the Carter et al. (2007) study? This is

unlikely, because the non-target images showed different objects like suns, crosses, or flowers. But why then did control participants more often perceived non-target stimuli at rivalry onset? Image-immanent features had been excluded. As Chong and Blake (2006) demonstrated initial onset may be driven by endogenous as well as exogenous attention. In this very case endogenous attention might be excluded, because control participants did not receive an instruction which drove their attention to a certain image, even though after the experiment some control participants judged the broken tool stimuli as „interesting“ or „funny“. It is likely that the tool stimuli attracted their attention (Elazary et al., 2008; Fecteau et al., 2006), because of the unusual functional part. The subsequent turning to the neutral stimulus would then result from an inhibition-of-return (IOR, a bias toward the unattended stimulus) described first by Posner and Cohen (1984). If attention is removed from a stimulus, there is a delay in responding to a subsequent stimulus presented at that location. Logically, it was first assumed that inhibition-of-return is an oculomotor process. If only oculomotor behavior induces this reorienting of attention, it would not be a proper explanation for findings in rivalry, for eye movements have been proved not to influence rivalry (Blake, Fox, McIntyre, 1971). But further research had shown sensory components to be involved, too (Klein, 2000; Fecteau et al, 2006). The underlying neuronal mechanisms reveal that both findings might be unified: it is the *Colliculi superiores* with their different layers, which induce the observed oculomotor behavior (intermediate layers) and the sensory components of the inhibition-of-return (superficial layers – for a detailed discussion about this topic see Fecteau et al., 2006). Activity in the superficial layers and the intermediate layers is independent, thus „sensory activity in the superficial layers need not lead to motor output“ (Kandel, 2000). But is the time course of the inhibition-of-return appropriate for findings in a rivalry paradigm? Usually an IOR is measured by presenting participants with a cue and a subsequent target at the cued location. The time between cue and target onset may be varied (**s**timulus **o**nset **a**synchrony, SOA) and reaction time to the target is ascertained. Reaction time is faster (compared to an uncued target) when SOA is short, and slower when SOA is longer. The crossover – where benefit changes to inhibition – lies between 200 and 300 ms. This is not

constant, because IOR time course is influenced by difficulty of target discrimination or response strategies (Klein, 2000). The author points out that „IOR appears to last for several seconds“. In my experiment time between the acoustic cue and the feedback tone was 700 ms. This timing would allow an inhibition-of-return to be built. To sum up, I state that in control participants exogenous attention and the subsequent IOR led to an increase of non-target percepts at rivalry onset.

Absolute frequencies of target / non-target percepts

In the experimental group the advantage of the initially perceived targets could also be shown for the absolute frequencies of perceived stimuli. Here, the target was more often seen than the non-target (see fig. 5). This advantage is stable within the experimental group itself and in comparison to the control group (see fig. 6). These data show a clear bias due to the intended action – participants had been required to attend the target stimulus (intact tool) as soon as they perceived the acoustic cue. The task was to take out an identical tool out of the tool-box after the end of the trial, which participants always did accurately. The correct actions confirm that experimental participants not only followed the instruction, but also focussed attention on the functional part of the tool and kept this information in working memory till the end of each trial. This is possible as shown in a recent study by Brouwer and van Ee (2006). Working with an ambiguously rotating sphere (which caused bistable perception) the investigators could show that voluntary control of one of the percepts was possible – even when tracking was impossible – provided that attention was focussed on the physical features of the stimulus. This condition was met in my experiment.

An alternative interpretation of the effect found in the experimental group is that tools per se capture attention, because they represent another object class than the non-targets (Elazary, Itti, 2008). If this had been the case one would expect no differences in absolute frequencies of percepts for intact and broken tools. Instead, participants in the experimental group perceived the intact-tool images more often while in the control group there was no difference. In other words: experimental participants perceived those target stimuli more often which helped to solve the task. This finding again supports the hypothesis that

action intention may influence the dominance of a stimulus. While in control participants no such effect could be found, a response bias toward the intact tools is unlikely. However, data from the control group are more difficult to explain. As mentioned above, across all trials the control group perceived non-target stimuli more often than targets. The same preference could be observed for the initial percept. Even though there is increasing evidence that the „choice“ of the first stimulus to be perceived and the predominance during sustained rivalry may be driven by different mechanisms (Chong, Blake, 2005; Carter, Cavanagh, 2007), it is likely that the same attentional process (IOR) underlies these findings, although the problem here may be that inhibitory processing should on the one hand be transient, on the other hand be effective during a longer lasting trial in sustained rivalry. This is what Tipper, Grison, and Kessler (2003) investigated: based on their attention experiments they claim an interrelationsship „between attention and memory processes in which inhibitory states are encoded into long-term memory in association with objects, locations, and other contextual information.“ The authors showed an inhibition-of-return-effect on a cued face, lasting longer than 13 minutes. These findings could not be explained by short transient mechanisms. Instead, it is probable that the observed inhibitions are object-based, and memory representations subsequently induced inhibition based on object and location contents. To find out if IOR might also be due to object-bound information Tipper and his colleagues (Tipper et al. 1999) let objects move to new locations while participants had to detect a target within the cued object – the results showed a strong impairment of detection, a finding which supports the notion that IOR is also due to object-based information. Jordan et al. (1998) reported that scene-based inhibition-of-return takes place when an object is to be detected, while object-based IOR was observed when the object had been detected. In a more recent study Paul et al. (2005) corroborated that inhibitory processes which drive IOR depend on object-based representations stored in memory.

Hancock and Andrews (2007) confirmed an inhibition-of-return effect in their rivalry experiments while working with exogenous attention on rivalry onset. I assume inhibition-of-return mechanisms for the present data, but further research is needed to understand these processes in more detail.

Alternation rates

As mentioned above, attention might affect both the initial onset of rivalry as well as the target stimulus to become dominant more often. Some investigators also found that attention influences the alternation rate (switching rate) of the two percepts (Chong, Blake, 2006; van Ee, van Dam, Brouwer, 2005), while in his pioneering work Breese (1899) did not. In the present experiment the alternation rate in the experimental group was reduced when target stimuli had been presented in a trial. This goes hand in hand with the task participants had to solve: They should pay attention to the functional part of the tool and make a decision whether the tool is intact or broken. In case of an intact tool observers had to keep the tool in memory and pick up this tool out of a box after the trial. It might be that the attentional load slowed alternations, as found recently in a study by Paffen et al. (2006). They presented their participants with a distractor task during rivalry and found that the more difficult the concurrent task the more the switching between the percepts slowed down (but never came to a standstill). Concerning the target trials of the present experiments no difference could be found in the control group between acoustic cue trials and no acoustic cue trials. In neutral trials (no target was presented) alternation rates in experimental participants slowed down when the acoustic cue was presented. For the cue was a signal to check for intact tools, this effect seems to mirror a time-consuming orienting reaction due to the learnt association between the cue and an intact tool. Interestingly, in the control group the alternation rate also slowed down when the cue was presented. Between the two groups no difference in alternation rates could be found. Might the decrease in alternation rates found in the control group be attributed to an influence of the acoustic cue per se? If this would have been the reason one would expect this bias also to occur in target trials. But this is not the case. A bias due to semantic meaning is unlikely, for why should a sun be semantically more prominent than, say, a star or a flower? However, there seems to be no plausible explanation based on the current data, because biases due to the physical properties of the neutral stimuli (see pretests) can be excluded. This also goes for the semantic meaning of the neutral stimuli: If these stimuli attract attention differently, this bias would have had to be observed in other trials.

Alternations after the acoustic cue

Participants had been instructed to check whether after the acoustic cue they were presented with an intact tool or not. Therefore the hypothesis was that after the cue a neutral stimulus should be suppressed, while the target stimulus should be dominant – in other words: The former suppressed target stimulus should gain dominance. In contrast, a former dominant stimulus should sustain its dominance. First, I want to address the findings after the groups had perceived the neutral stimulus and the acoustic cue: Comparing the two groups, the experimental group tended to perceive the target more often than the control group, while control participants perceived the neutral stimuli more often than experimental participants. Both findings failed to reach significance. Furthermore I was interested, if there was a difference of which stimulus was perceived after the cue. Control participants perceived the target stimulus and the neutral stimulus equally. So far, these data confirm reports from other studies – it is difficult to bring a suppressed target stimulus to dominance by induced endogenous attention. Chong, Tadin and Blake (2005) employed endogenous attention in their rivalry experiment and report a prolongation of dominance, but they did not find an effect on suppression phases. Interestingly, when comparing the neutral-neutral and the neutral-target condition within the experimental group (see table 4), data show that participants perceived the target stimulus significantly more often. In other words: Here, as to my knowledge, for the first time, endogenous attention helped a suppressed stimulus to become more often dominant than its neutral counterpart without concurrently carrying out a motor movement (see Maruya et al., 2007). It is assumed that suppression is a multi-stage phenomenon – psychophysical, imaging and neurophysiological studies suggest suppression to be implemented at the monocular and V1 level as well as higher cortical levels (Freeman et al., 2005). The depth of suppression along these pathways is not identical, but increases the higher the brain level. Attention itself can influence information processing at these multiple levels of the visual hierarchy (Kastner, 2004). Thus, it may be that attention – to effectively „boost“ a suppressed stimulus to dominance – has to influence several properties of rivalry to varying degrees in the visual pathway. On the one hand, because of failure to reach significance

when comparing the two groups, data are in line with current research. On the other hand, the observed findings in the experimental group encourage further research on the effects of endogenous attention on suppressed stimuli.

Which stimulus did participants perceive after having been cued? The hypothesis was that the target stimulus sustains dominance after the acoustic cue. Comparing the two groups, the experimental group perceived the target stimulus more often, but the effect could not be valided statistically (see table 3). In contrast to this, a clear effect showed in control group – here, participants perceived the neutral stimulus significantly more often than experimental participants. The above discussed inhibition-of-return effect seems to mirror the bias toward neutral stimuli. While within the control group no difference between the target-target and the target-neutral condition was found (see table 4), in the experimental group a significant difference in favor of the target-target condition could be observed (see table 4). Again, the data are in line with other studies, which found an influence of endogenous attention on dominance of a target stimulus. Hancock et al. (2007) confirmed this influence, but reported that it was not due to an increase of mean dominance periods of the target, but instead a decrease of the mean dominance periods of the non-target. These findings contrast with another study carried out by Chong et al. (2005), who found a prolongation of target dominance periods. However, attention is thought to increase the effective contrast of a certain stimulus (Carrasco, Ling and Read, 2004), the magnitude of this benefit varies between 30 % and 70 % . In their rivalry experiment Chong and Blake (2005) found an attentional increase in apparent contrast of 47 %. The different findings of the Hancock and Chong studies might be due to the fact that Hancock et al. presented their participants with a cue prior to the rivalry session – but participants might have had difficulties to attend to a (suppressed) stimulus they were not consciously aware of. Brouwer and van Ee (2006) claimed exogenous (that is physical properties) stimulus characteristics to be sufficient for endogenous influences. As a stimulus they used an ambiguously rotating sphere and found independent processing and influences on rivalry for both motion and form. Thus, it seems likely that attention focuses on stimulus properties. In my experiment it was the functional part of a certain tool which was in focus of the participants' attention.

Phase duration

How long had the target and the non-target stimuli been perceived during the trials and do these durations show an advantage for one or the other stimulus? In the experimental group in phases from 2 seconds up to 12 seconds duration no significant difference could be found between duration of target versus non-target percepts (see fig. 7a). However, some trends can be seen: Phases shorter than 2 seconds were more frequent for target percepts, the same finding goes for phases up to 10 seconds and for 12 seconds. (Note that participants had to report their percepts every two seconds, thus, it may be that a switch in between might have been missed.) For the long phases reported here, „n“ was very small. Taken together, the advantage of the absolute frequencies of target percepts for experimental participants as reported above, could not be attributed to certain phase durations. On the other hand, it turned out that in the control group phase durations of 4 seconds up to 6 seconds for the non-target stimuli turned out to be significant (see fig.7b). The above reported finding of absolute frequencies of non-target percepts may be attributed to phases from 4 to 6 seconds. Comparing the two groups, it is the 4-seconds phase which reveals differences: an advantage for the non-target in control participants and an advantage for the target in experimental participants. Short phases of 1 to 2 seconds duration are considered to reflect an unstable system (Mamassian, Goutcher, 2005). The trend observed for the long phases mentioned above may get significant when prolonging the trials and let participants do more trials. In fact in other studies trials were longer (e.g. Paffen et al. 2006). However, an action intention might have the power to instantiate sustained attention. So why is the effect only a small one? In their report Sarter et al. (2001) worked out those variables, which maintain sustained attention: a high event rate combined with the unpredictability of event timing (event asynchrony) puts a high attentional load on participants, because the cue appeared randomly. Demands on working memory had also been high, for participants had to report their percepts and keep in memory the tool to solve the subsequent task. Thus, two alternative interpretations of these findings are possible: it was difficult for participants to sustain their attention, because of high cognitive load. Or, even though it had been shown that action representation may facilitate object recognition (Helbig

et al., 2006), these representations are to weak to influence attentional processing over a certain amount of time. In a recent study Maruya et al. (2007) found a positive effect of actions – when participants carried out a movement with the computer mouse during rivalry with moving targets, dominance durations were prolonged and suppression durations abbreviated when the target stimulus' movement and the executed movement were congruent. What is the difference between an ongoing action and a representation of an intended action which might matter in the case of rivalry? It is reasonable, that visually guided actions such as performed in the Maruya experiment are processed in the dorsal stream of the visual pathway (Goodale and Milner, 1992; see also section 1.1). Fang and He (2005) showed that a difference of neural activities in the two visual pathways exist during dominance and suppression: while in the dorsal stream activity remains constant, in the ventral pathways it fluctuates during rivalry. Thus, if the visually guided actions in Fang and He's participants had been continously represented, these representations could have constantly influenced the brain sites of rivalry. In contrast, viewing tools such as in the current experiment „tends to activate more ventrally located regions" (Lewis, 2006) of the brain such as the bilateral **p**osterior **M**iddle**T**emporal**G**yrus, parts of the **I**nferior**T**emporal**C**ortex and **F**usiform**C**ortex and further parts of the frontal as well as the parietal cortex (see Lewis 2006, for a detailed description). Fluctuating neuronal activities of the intended representations in the pMTG, ITC and FC during rivalry in contrast to sustained acitivities of the representations of visually guided action in the parietal parts, might have built the basis for the differences found and just discussed.

3 Experiment 2: Learning and Binocular Rivalry

The action intention in the action intention experiment turned out to influence rivalry, at least in part. Would another cognitive task also be sufficient to influence binocular rivalry? A study mentioned earlier (Yu et al., 1992) points to recognition as a powerful variable. Yu and Blake (1992) showed that a meaningful object like a Dalmatian dog, even when it is presented in a camouflaged manner, can have an advantage over a neutral stimulus: participants in this study reported prolonged dominance phases of the whole object (the dog) compared to a random dot stimulus with the same luminance and contrast. The investigators concluded that rivalry „is sensitive to object-related, configural properties of a stimulus“. This statement refers to the underlying object representation. A dog is a highly overlearnt stimulus and its representation was the key player for rivalry to be influenced. In the discussion the authors did not focus on the degree of learning as a possible influencing variable. Thus, one question remains: can a newly learnt stimulus affect rivalry top-down? If so, what is the difference between newly learnt stimuli and highly overlearnt stimuli such as tools? As Baker, Behrman and Olson (2002) pointed out „experts process images in a qualitatively different way from novices“ (p.1210). By single-cell recording in the inferotemporal cortex of monkeys they found that with an increase in learning neurons showed enhanced selectivity for the whole pattern and task-relevant individual parts of the patterns learnt previously, whereas neurons in „novices“ (monkeys who just started learning the patterns) may show responses according to their preferred stimulus, but do not show selectivity induced by the task affordance.

In view of these facts it remains an open question, if an artificial, meaningful, newly learnt stimulus has the same effect on binocular rivalry as a highly overlearnt stimulus.

Thus, the main hypothesis of my character experiment was that a previously learnt (meaningful) stimulus will be pushed to dominance and frequencies of reported target percepts (predominance) will increase.

3.1 Experiment (Learning experiment)

In this experiment I address the question if, mediated by top-down attentional processing, a newly learnt stimulus in part containing semantic components affects rivalry. The idea was to let participants acquire completely new knowledge within a learning paradigm. Therefore I wanted to focus on knowledge which was (i) easy and quick to learn, but which (ii) should tap on unknown skills, to ensure the shown performance to be fully under experimental control. Another important demand was (iii) that the acquired knowledge should have a semantic component and finally (iv) should be easy to test under rivalry conditions. To meet these conditions participants in the first part of this experiment learnt a Chinese character. I chose one of the easy characters, written in just six strokes, which is easy to memorize: 米 . The character was associated with an acoustic cue, which served as a cue to draw top-down attention to this character (target stimulus). After passing these tasks participants took part in the rivalry experiment.

3.2 Methods

Participants

Twentyseven participants (age 22 – 51 years; mean: 29.8 years; thirteen female) participated the character experiment. No participant could speak or read and write Chinese or Japanese, no participant had close contact to the Chinese or Japanese language. One participant with some knowledge of Japanese language was discarded. All participants had normal or corrected-to-normal vision and no restrictions in hearing. All participants were naive to the hypotheses and the purposes of the experiment.

Task

In the rivalry experiment both experimental and control participants were to report their current percepts whenever an acoustic prompt occured every two seconds. The experimental group was presented with an additional acoustic cue, which required participants to report if the target stimulus (Chinese character) changed after the acoustic cue had been given. Control participants were told to participate in a concentration experiment and were instructed to ignore the distracting tone (the prompt).

Apparatus

The experiment was run on the same apparatus used in the former experiment. However, participants reported their percepts via a common computer mouse.

Stimuli

Visual stimuli:

Visual stimuli were identical for both the experimental and control group. Every stimulus consisted of a black-framed square filled with a grey pattern, which helped participants to fuse the pair of stimuli. In the center of the square a hexagon, colored either red or green, was located. Within the hexagon the rival stimulus was situated. Three categories of stimuli were presented: neutral ones (the ones used in experiment I), which only showed either a horizontal or vertical grating or a triangle; „semi“-neutral stimuli, which showed a stylized

sun, star, or a flower, and the target stimulus, which consisted of the Chinese character. The reason to include stimuli with semantic content (sun, flower and so on) was to avoid a „semantic pop-out“ of the Chinese character picture, when presented against only horizontal or vertical bars. The Chinese character [米] was drawn by hand with deep black ink and exact straight lines (no calligraphy style). It had a size of 8 cm x 7 cm and was presented on a white rectangle of 18 cm x 14,5 cm on a black screen. All stimuli had the same line thickness to avoid differences in physical appearance. Red and green background colors had the same brightness and luminance.

Auditory stimuli:

Two different tones were used.

* A 500Hz-prompt, presented at 48 dB, was repeated every two seconds and served as a signal for participants to report their current percept.

* An acoustic cue (Windows© XP Professional, 2002, notify.wav), which served as a conditioning stimulus in the experimental group. The acoustic cue was presented at 48 dB and appeared at random times and at most four times per trial.

Pretests

I refer to section 2.2.1.5 in which I described the tests in detail. During the pretests participants not only checked the tool stimuli for usability, but also tested the Chinese character stimulus which served as the target image in this experiment. Originally I asked participants to judge two other Chinese characters. One of them did not rival enough, presumably for too many corresponding points to the other images. The second character was rated to be „not as easy to memorize“ as the one I finally included. All participants judged the final one as to be easy to memorize mainly because of its symmetry. No pretest-participant took part in the main experiment.

Design

For the experimental group the experiment was divided into two parts, a learning part and a rivalry part. The control group only participated the rivalry part. For both groups written instructions were presented on the screen.

Experimental group:

Task 1 – Memorize a Chinese character. Participants learnt the character in a visuomotor manner: they were seated in front of the monitor with a distance of 80 cm, a pen and a sheet of paper right in front of them. On the screen the Chinese character appeared in a stroke-by-stroke-manner, and participants were requested to draw the character stroke-by-stroke as shown on the screen.

Task 2 – Recognition task. Participants were presented with 20 visual stimuli in random order, 10 of them arbitrary patterns made of a different number of strokes (non-targets) and 10 of them the Chinese character (target). Participants were to report via mouse-click what was presented. Immediately after the report, the computer gave feedback whether the answer was correct or not.

Task 3 – Discrimination task. Participants were presented with target stimuli and non-target stimuli. The non-targets (n = 9) had the same number of strokes as the target character (n = 11), but differed in how the strokes were placed. One Chinese character, similar to the target, was also presented and served as an indicator whether participants had learnt the target character: this non-target was a character identical to the target except for one additional small stroke on its top. Stimuli were presented in random order and participants were given immediate feedback.

Task 4 – Introduction of the associated acoustic cue. Participants were conditioned to an acoustic cue, which preceded the target stimulus. The acoustic cue served as a stimulus that signaled possible changes of the target. The target was presented under two conditions: together with or without the cue. If the target stimulus appeared in combination with the cue, participants were to report whether the target's appearance had changed. The target was presented 18 times, in nine of which it changed its appearance. The change of appearance was defined by removing one or more strokes for 70 ms after exposure of 800 ms. After the removing intervall the target again was fully visible for 500 ms.

As in the former trials participants received immediate feedback whether their observation was correct or not.
Rivalry experiment. See „trial events“ for details.

Control group:
For the control group the experiment consisted of one part only. Participants were told that the purpose of the experiment was to find out how well one can focus on visual stimuli when disturbed by auditory stimuli. Visual and auditory stimuli were the same for this group as for the experimental group. Before running the 19 rivalry trials participants learnt to use the stereoscope and to report their current percept via mouse-click every two seconds. The experiment lasted for approximately 25 minutes.

Trial events
Nineteen trials, lasted 42 to 52 seconds each, depending on how often the acoustic cue was presented. Every trial started with the word „ready“ in white. As soon as the enter key was pressed, the pair of stimuli appeared on the screen. After 1000 ms of visual stimulus presentation the first prompt required participants to report their current percept. In the entire trial prompts appeared every 2000 ms. If the acoustic cue was presented in a trial, it appeared 1000 ms after the prompt and the next prompt appeared 700 ms after the acoustic cue. During the whole trial the visual stimuli were presented constantly (see also figure 4, section 2.2.1).

Procedure
All participants were asked if they had any restrictions in vision or hearing. Some information was given about binocular vision and the function of stereoscopes. Trials were recorded in logfiles. Performance in introduction tasks was also recorded and later served as a control whether participants had learnt the character properly. The experiment lasted for approximately 40 minutes. Participants were encouraged to take a short break if necessary. After the experiment participants were questioned about their knowledge of Chinese or Japanese. All persons participated voluntarly and did not receive a fee.

Data analyses

Data were analysed as in the former experiment. For definitions see section 2.2.1. Logfiles again built the basis to determine:

* the absolute frequencies of the initially perceived target stimuli
* the absolute frequencies of the target and non-target percepts over all trials
* phase durations
* alternations after the acoustic cue.

3.3 Results

Eight out of 475 trials had to be discarded from analysis for too many missed responses (4) and for containing responses to only one stimulus (4). Outliers: eight single responses out of all trials were discarded, because reaction time to the acoustic cue was too fast and considered to be artifacts due to anticipation of the next prompt.

Initial target stimulus / non-target stimulus percepts

Learning a Chinese character had an influence on the perceived stimulus at the onset of binocular rivalry.

Initial stimulus percepts in experimental group.

In the experimental group the target stimulus became dominant more often than the non-target stimulus [Mann-Whitney U 8512; $p < 0.0001$].

Initial stimulus percepts in control group.

No difference could be shown between target stimulus and non-target stimuli in the control group [Mann-Whitney U 8001; $p = 0.9011$].

Initial stimulus percepts in experimental vs control group.

The target stimulus was initially perceived more often in the experimental group than in the control group [Mann-Whitney U 8344; $p = 0.0231$]. The non-target stimulus was initially perceived more often in the control group [Mann-Whitney U 8343; $p = 0.0231$].

Target stimulus / non-target stimulus percepts

Learning a Chinese character also influenced the absolute frequencies of perceived stimuli.

Absolute frequencies of target vs non-target percepts across all trials.

The experimental group perceived the target stimulus more often than the neutral stimuli [$t = 7.849$; $p < 0.0001$]. The control group showed no differences

in perceiving the target vs non-target stimuli [t = 0.3390; p = ns]. In comparison to the control group the experimental group perceived the target stimulus more often [t = 2,813; p = 0.0052].

Concerning the perception of the non-target stimulus the control group in comparison with the experimental group perceived the non-target stimulus more often [t = 4.893; p < 0.0001].

The target stimulus was perceived more often in the experimental group than in the control group [t = 0.0052; p < 0.05]. In contrast the control group reported more non-target percepts – this difference proved to be extremly significant [t = 4.893; p < 0.0001].

Graphs of absolute frequencies of target and non-target percepts per every two-seconds-phase of all trials.

The figures below show the absolute frequencies of target stimulus and non-target

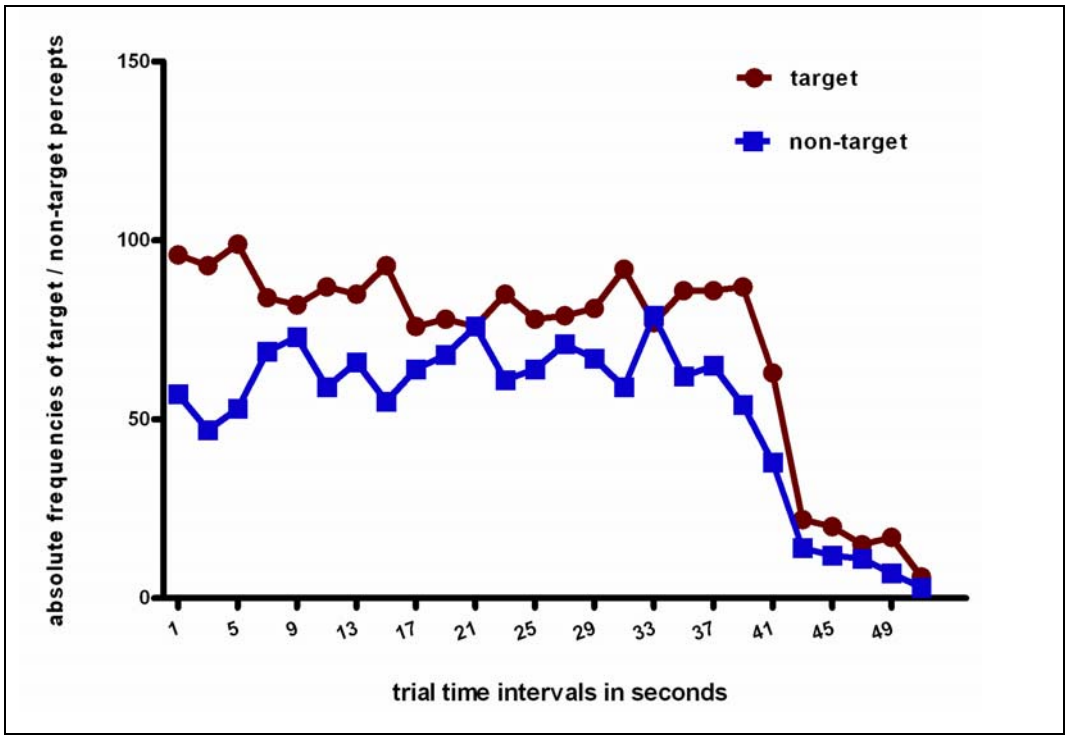

Figure 9: Experimental group: absolute frequencies of target stimulus and non-target stimulus percepts of all trials. Frequencies of percepts as reported every two seconds are shown.

percepts that had been reported after the prompt, which had appeared every two seconds. Frequencies contain data of all trials. Figure 9

shows data of the experimental group, while figure 10 shows the data of the control group. At the end of the trials the curves decrease, because the acoustic cue was given one to four times at most per trial. The more acoustic cues were given the longer the trial lasted. While numbers of trials with one, two, three, and four acoustic cues were identical, long lasting trials were less frequent.

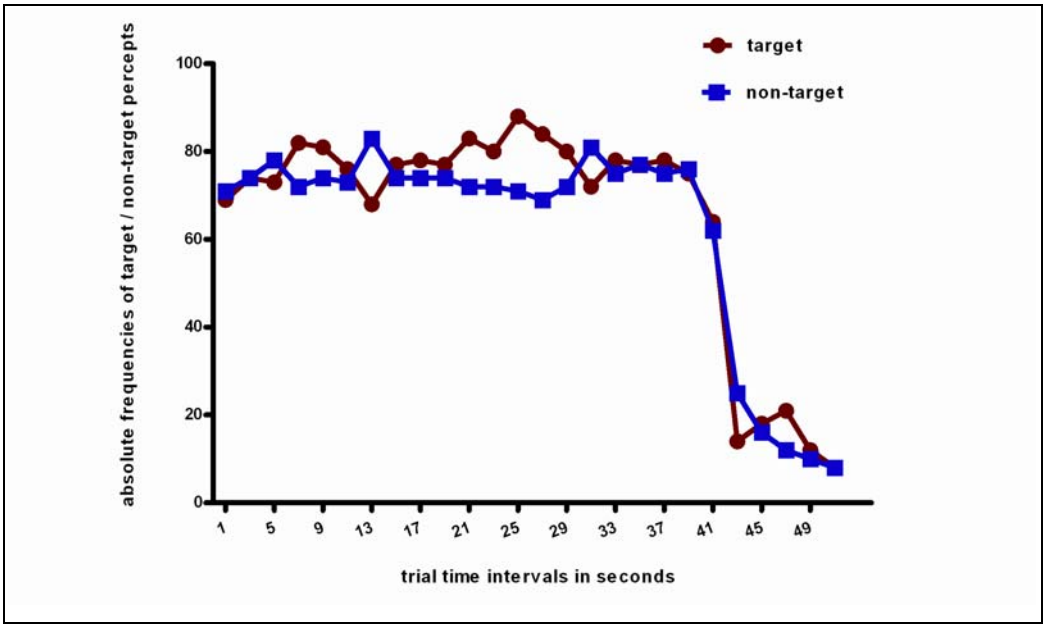

Figure 10: Control group: absolute frequencies of target stimulus and non-target stimulus percepts of all trials. Frequencies of percepts as reported every two seconds are shown.

Switching rates

Switching rates show how often the two percepts alternated within a trial. For this analysis trials consisting of target and non-target stimuli and those containing either target or non-target stimuli were taken into account. Further trials with two neutral stimuli with a) the acoustic cue and b) without the acoustic cue were analysed to check whether the acoustic signal per se induces speeding or slowing down of switching. To test whether this auditory signal influenced target trials this also was analysed.

Switching rates across target and non-target trials.

In the experimental group the switching rate was lower in target trials than in neutral trials [t = 3.666; p = 0.0003]. The same effect was found in the control group [t = 2.784; p = 0.0058].

Comparing switching rates of the experimental and the control group in target trials, no significance could be found [t = 0.1402; p = 0.8886]. The same result was found in non-target-trials – here, too, switching rates of both, the experimental and the control group did not differ significantly [t = 1.381; p = 0.1693].

Switching rates of neutral trials with and without acoustic cue.

To check if there was a bottom-up-influence of the acoustic cue per se, switching rates of neutral trials with acoustic cue were tested. In neutral trials without any target stimulus, but with acoustic cue there was no difference in switching rates between the experimental and the control group [t = 0.1581; p = 0.8747]. The same result was found in experimental vs control group concerning neutral trials without any target stimulus and without acoustic cue [t = 1.335; p = 0.1877].

When analysed separately, the control group showed a significant difference in switching rates of neutral trials with acoustic cues and without acoustic cues [t = 2.444; p = 0.0171]. This difference is bigger in the experimental group [t = 4.914; p < 0.0001].

Switching rates of target trials with and without acoustic cue.

A look at target trials with vs without acoustic cues shows no difference in the control group, whereas in the experimental group this difference is extremly significant, with more switchings in those trials without acoustic cue [t = 5.158; p < 0.0001].

Phase durations

This analysis is mainly concerned with the question how long participants perceived a target or a non-target stimulus and how long these phases lasted.

Skewness of phase durations. In binocular rivalry experiments dominance phases normally follow a left skewed distribution. Therefore phase durations of the following conditions were analysed graphically: phase durations of target percepts and non-target percepts in the experimental group (figure 11) and phase durations of target percepts and non-target percepts in the control group (figure 12). All phase durations are left skewed. Perception times for the different phases were as follows: phase 1 at most 2 seconds, phase 2 at most 4 seconds, phase 3 at most 6 seconds, phase 4 at most 8 seconds, phase 5 at most 10 seconds, phase 6 at most 12 seconds.

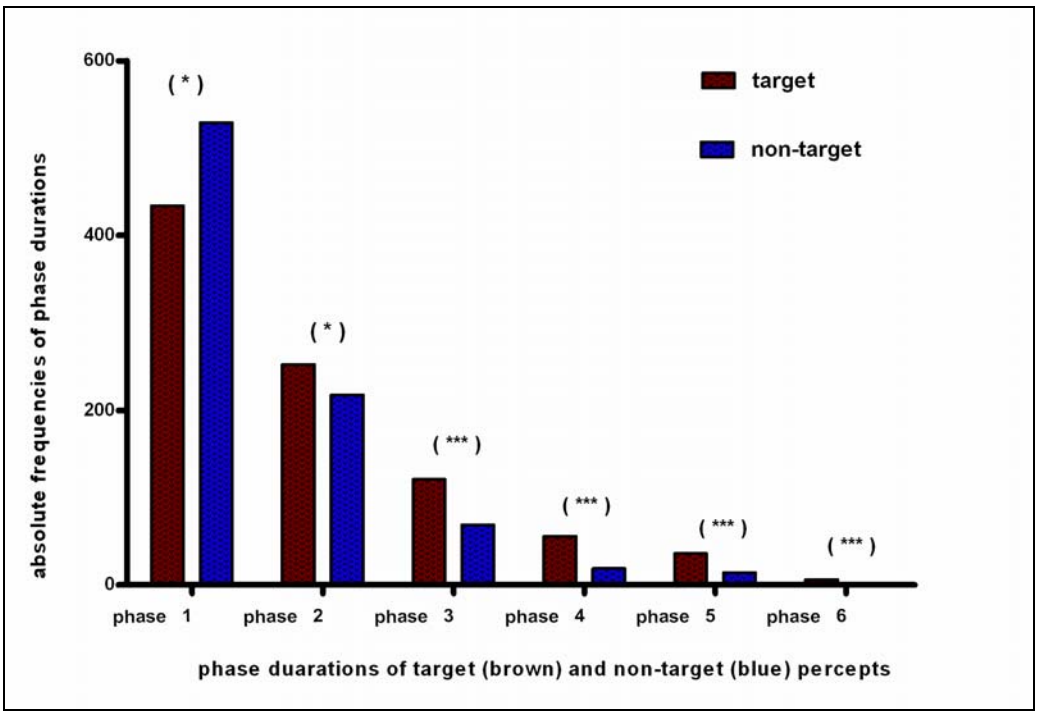

Figure 11: Learning experiment – experimental group: phase durations of target (brown) and non-target (blue) percepts. . Phase 1 includes perception times of at the most two seconds, phase 2 four seconds, phase 3 six seconds, phase 4 eight seconds, phase 5 ten seconds and phase 6 twelve seconds

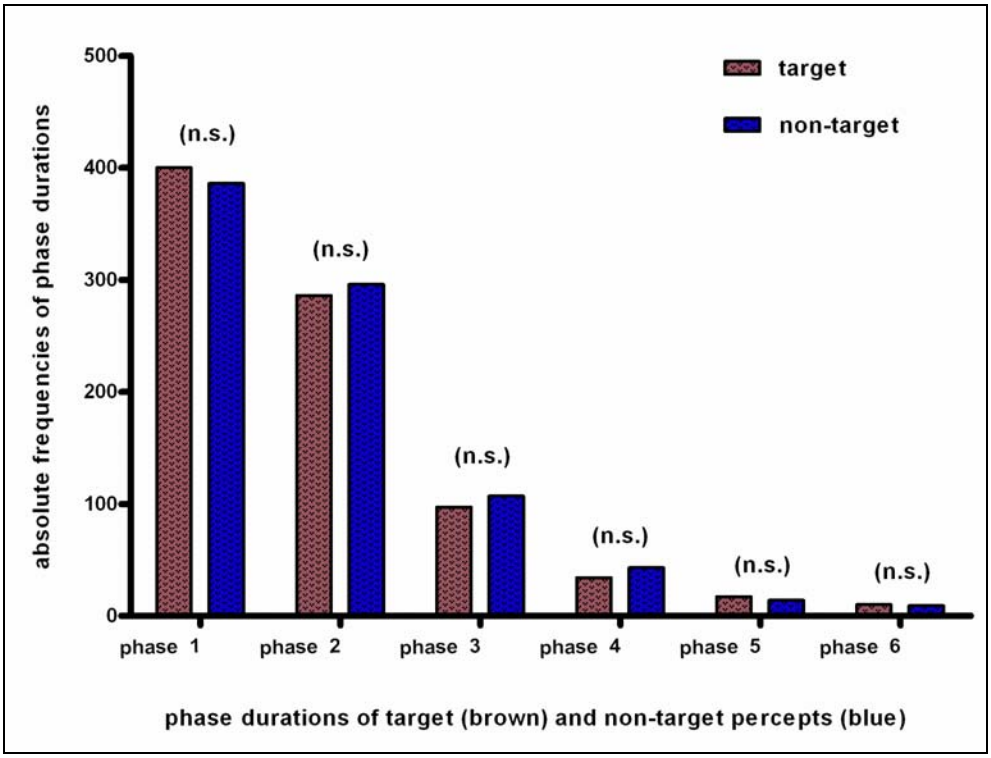

Figure 12: Learning experiment – control group: phase durations of target (brown) and non-target (blue) percepts. . Phase 1 includes perception times of at the most two seconds, phase 2 four seconds, phase 3 six seconds, phase 4 eight seconds, phase 5 ten seconds and phase 6 twelve seconds

When looking at each phase separately, the following results were obtained:

In *phase 1* no difference between absolute frequencies of phase 1 percepts of target and non-target stimuli could be found in the control group [Mann-Whitney U = 11890; p = 0.8703]. This was not the case in the experimental group, in which the absolute frequencies of phase 1 percepts for non-target stimuli were significantly higher [Mann-Whitney U = 9730; p = 0.0034].

In *phase 2* no difference between absolute frequencies of target and non-target percepts could be found in the control group [t = 0.2347; p = 0.8146]. The experimental group reported more percepts of the target stimulus [Mann Whitney U = 10390; p = 0.0210], which turned out to be significant.

In *phase 3* again no difference was found in the the control group [Mann-Whitney U = 11480; p = 0.4562]. An extremly significant difference was found in the experimental group [Mann-Whitney U = 9060; p < 0.0001], in which more phases of target percepts had been perceived.

In *phase 4* target vs non-target percept phases were equally perceived in the control group [Mann Whitney U = 11700; p = 0.4238]. In the experimental group phases of target percepts dominated significantly [Mann Whitney U = 9598; p < 0.0001].

In *phase 5* both, target and non-target percepts did not differ significantly in the control group [Mann Whitney U = 11700; p = 0.4238], whereas in the experimental group target phases dominated significantly [Mann Whitney U = 9960; p = 0.0006).

Phase durations of non-target percepts in experimental vs control group:
After analysing each group separately, frequencies of each phase duration (phases 1 – 5) of non-target percepts were analysed to learn about possible differences in experimental vs control group. Table 5 summarizes these results.

Frequencies of *phase 1* of non-target percepts showed an extremly significant difference between the experimental and the control group. Participants in the experimental condition reported more phases of non-target percepts [Mann-Whitney U = 8836; p < 0.0001].

For *phase 2* this result reverses: here, the control group reported more phases of non-target percepts [Mann Whitney U = 8676; p < 0.0001, extremly significant].

Concerning frequencies of *phase 3*, the control group again perceived more phases of non-target stimuli than the experimental group [Mann-Whitney U = 9996; p = 0.0039].

For *phase 4* most frequencies of non-target phases were observed in the control group [Mann Whitney U = 10590; p = 0.0055].

Phase 5 analysis showed no difference in frequencies of non-target phase percepts between the experimental and the control group [Mann Whitney U = 11730; p = 0.8823].

Table 5: Learning experiment: non-target phase durations in experimental vs control group

non-target phases	experimental vs control group
phase 1	(***) experimental group > control group
phase 2	(***) experimental group < control group
phase 3	(**) experimental group < control group
phase 4	(***) experimental group < control group
phase 5	n.s.

Phase durations of target percepts in experimental vs control group:
This analysis shows the frequencies of phase durations (again for phases 1 – 5) of target percepts and about the differences between the experimental and the control group. All results are summarized in table 6.

For phase duration of *phase 1* target percept frequencies were higher in the experimental group, but this difference was too slight to be significant [Mann-Whitney U = 11290; p = 0.3529].

For *phase 2* target perceptions I could not find a difference between the experimental and the control group [Mann-Whitney U = 11200; p = 0.2496].

Frequencies of *phase 3* of target percepts differed significantly [Mann-Whitney U = 10450; p = 0.0314]. Here, the experimental group perceived more target phases.

The result, which was found for frequencies of phase 3, was also found for *phase 4*. Here, the experimental group again perceived more target phases [Mann-Whitney U = 10460; p = 0.0082].

Phase 5 target percepts were more frequently in the experimental group than in the control group [Mann-Whitney U = 10510; p = 0.0094].

Table 6: Learning experiment: target phase durations in experimental vs control group

target phases	**experimental vs control group**
phase 1	n.s.
phase 2	n.s.
phase 3	(*) experimental group > control group
phase 4	(**) experimental group > control group
phase 5	(**) experimental group > control group

Alternations after acoustic cue

This analysis shows the conditions of stimulus alternation after participants perceived the acoustic cue (conditioning tone). Four alternating conditions had been possible: neutral-neutral, neutral-target, target-target and target-neutral. All following results reported concern the differences between the experimental vs the control group and are summarized in table 7.

Neutral-neutral alternations after acoustic cue.

Repeated perception of a neutral stimulus after participants had perceived a neutral stimulus before the acoustic cue was more frequently in the control group [t = 2.890; p = 0.0083].

Neutral-target alternations after acoustic cue.

Concerning the alternation from a neutral stimulus to the target stimulus after the acoustic cue had been perceived, a slight difference could be shown between the two groups [mean of alternations in the experimental group: 8,3, and mean in the control group: 7,5], but after statistical analysis this difference turned out not to be significant [t = 0.6618; p = 0.5147].

Target-target alternations after acoustic cue.

A difference between the means like the one which was found in the neutral-target condition was also observed in the target-target condition [mean in experimental group: 9,0 and control group: 6,6], but was not statistically significant [t = 1.533; p = 0.1390].

Target-neutral alternations after acoustic cue.

The probability for a target stimulus to alternate to a neutral stimulus after perception of the acoustic cue was lower for the experimental group. The result turned out to be extremly significant [t = 4.185; p = 0.0004].

Table 7: Learning experiment: alternations after acoustic cue in experimental vs control group

alternations	**experimental vs control group**
neutral-neutral	(**) experimental group < control group
neutral-target	n.s.
target-target	n.s.
target-neutral	(***) experimental group < control group

The hypothesis was that the experimental condition should have produced differences of which stimulus had been perceived after the acoustic cue, the results of both groups are described separately. All results are shown in table 8.

Neutral-neutral compared to neutral-target alternations after acoustic cue.

In the experimental group more alternations to the target stimulus after perception of the neutral stimulus had been registered. This result is extremely significant [t = 4.409; p = 0.0002]. In the the control group alternations to target and to neutral stimulus were the same [t = 0.5434; p = 5923].

Target-target compared to target-neutral alternations after acoustic cue.

After the perception of the target stimulus the experimental group tended to perceive the target stimulus again after being cued [t = 3.823; p = 0.0008]. The control participants did not show any difference [t = 0.9045; p = 0.3755].

Table 8: Learning experiment: comparison of neutral-neutral condition vs neutral-target condition; comparison of target-target condition vs target-neutral condition in the experimental and the control group respectively.

comparison of alternations	experimental group	control group
neutral-neutral vs neutral-target	(***) neutral-neutral < neutral target	n.s.
target-target vs target-neutral	(***) target-target > target-neutral	n.s.

3.4 Discussion

The purpose of the character experiment was to test whether a previously learnt new stimulus influences binocular rivalry. Before participating the experiment, all observers had to draw and learn the Chinese character. Research on Asian language acquisition on learning a character by writing it in a stroke-by-stroke manner had proved to be a useful strategy for beginners (Shen, 2005). Further the movement per se had turned out to be crucial for the representation and subsequent recognition (Longcamp et al., 2005). For this reason participants viewed a stroke-by-stroke animation on the computer screen which they wrote down simultanously. Karni and Sagi (1993) – using a perceptual discrimination task – studied the time course of learning. They found out that learning „was driven by the sensory experience acquired at the first session“, than showed a latent phase in which no improvement could be found. The investigators could measure large improvements on discrimination learning after training the following day. Because I only wanted to make sure participants could built a representation, but were not required to disriminate several characters, they underwent a single learning session (writing) and two recognition tasks. In learning and memory research it is known that several kinds of feedback exist to establish learning (Mory, 2004). To help participants to successfully learn the character in a single session participants had been provided with immediate feedback by giving a simple statement („correct“, „wrong“), which was found to be effective (Mory, 2003). Additionally, in the second recognition task another character with one additional stroke appeared, but all participants rejected this probe as to be incorrect. Because no errors occured in the recognition tasks proper learning could be assumed.

Initial percept

In the character experiment I could show that a previously learnt new stimulus influenced binocular rivalry. This influence clearly affected the onset of rivalry: in experimental group the initial image to be perceived mostly had been the Chinese character. This was true within the experimental group as well as in comparison to the control group. Within the control group no such effect could be found. As already mentioned in the discussion of the former experiment, two

recent studies have shown that endogenous attention influences the onset of rivalry (Chong, Blake 2006; Carter, Cavanagh, 2007) by increasing the apparent contrast of a certain stimulus (Chong et al., 2007, Carrasco et al., 2004). In Experiment 1 it seemed likely that feature-based attention on the functional parts of the tools influenced rivalry. But would this also be true for whole objects? Recently Mitchell, Stoner, and Reynolds (2004) could establish a connection between rivalry and object-based attention. They cued attention to one of two transparent surfaces and showed an advantage for the cued target during rivalry. Further the authors concluded that rivalry also affected competition between high-level object representation. But this is not the only possible interpretation: attention acts on different levels of the visual pathways (Kastner et al., 2004), and thus the claimed object-based attentional influences might be the result of multilevel attentional processing. However, Mitchell and his colleagues (2004) clearly showed that object-based attention influences dominance of rivalry. Persons unexperienced in writing Chinese characters also learn and perceive a character as a *whole visual* object (Shen, 2005), and are subject to the rules of reading acquisition (Ramus, 2004) of words. Participants in my experiment had no inexperience in writing or speaking Chinese or Japanese, and therefore represented the character as a whole object. I conclude that object-based, endogenous attention helped this target stimulus to become initially dominant. If the target image as representing a different object category as compared to the neutral stimuli had attracted attention, the same effect would have had to be found in the control group. This was not the case. Differences in physical features of the stimuli could also be excluded, for the character stimulus had been tested in pretests.

Absolute frequencies of target / non-target percepts

The advantage object-based attention had established on the onset could also be seen in the absolute frequencies of target percepts across all trials for both within the experimental (see fig. 8) and compared to the control group (see fig. 9). Further, attentional influences also showed up after participants had been presented with the acoustic cue (see tables 7, 8). Chong et al. (2005) found that endogenous attention prolonged dominance durations of their target stimulus. But this is only possible when the target stimulus is already seen, because

participants can only focus their attention on a stimulus which is consciously perceived. While in the current experiment the cue had appeared randomly, it appeared during the dominance phases of the target and non-target stimuli. Thus, when object-based attention strengthen the target stimulus one expects the affected dominance periods to prolong, and, if object-based attention influences a suppressed stimulus as well, one also expects quantitatively more dominance periods of the target, for the former suppressed target will become dominant. The dominance prolongation Chong, Tadin and Blake (2005) reported is found, when considering the alternation after the cue had been presented: in the experimental group the target stayed longer dominant instead of being suppressed, while no such effect was found in the control group. Attentional processing helped the target stimulus to gain an advantage. Even though there are differences in the recognition of a 3-D-object and an alphanumerical pattern (see Bruce et al., 2003), it is likely that attention affected the *whole* object, for naive participants to Chinese do not know the orthographic construction of characters. 28 distinguishable types of strokes exist (Huang, Liao, 1981), all to which the participants in the current experiment had been naive of. Effects on suppression could not be found when comparing the experimental and control group. In rivalry research it is known, that mechanisms which drive dominance and suppression seem to be mutually distinct (e.g. Sobel at el., 2002; Freeman et al., 2005). Interestingly, when looking at the experimental group alone when the acoustic cue had been presented, participants perceived the target stimulus much more often than the neutral stimulus (see table 8). In other words: the cue helped the target to become dominant after it was suppressed. This effect could not be observed in control group (see table 8). How might this difference to some other findings (Sobel et al., 2002; Chong, Tadin, Blake, 2005) be explained? One should be aware of the fact that the current finding is only a weak effect, because it only affected experimental participants, but could not be shown in comparison to the control group. While Sobel et al. (2002) added a global context to their rival stimuli to learn whether contextual information would influence dominance and suppression respectively, in the current experiment an acoustic cue served as a

„dropped anchor“ during suppression which might have helped bringing the former learnt association into awareness again. Thus, it might have been easier for the target stimulus to escape suppression.

Switching rates

Did the attentional effects discussed so far also influence the dynamics of rivalry? Comparing the two groups, no such effects could be found – the alternation rates were the same for target and non-target trials respectively. A strong attentional effect appeared in the experimental group – here, in target trials switching rates decreased, an observation which is in line with the former learnt association between cue and target stimulus and the task experimental participants had to solve. They had been required to check for changes in target appearance. This task demanded a longer observation time, which subsequently prolonged target dominance and decreased the switching rates. In line with this is the finding of decreased alternations even in neutral trials, an effect due to the former pair-association learning and subsequent attentional processing. However, this effect diminished when both groups are compared. These findings fit to those of Meng and Tong (2004), who compared attentional effects on alternations in binocular rivalry and bistable figures such as the Necker cube. The authors found only a weak attentional effect on alternation rates in rivalry. Interestingly, alternation rates in the current control group were also decreased. This is not due to endogenous attention, because the control participants had only been required to concentrate and report their percepts. A bias due to the physical appearance of the target stimulus can be excluded. Instead, it is likely that the target stimulus became salient compared to the neutral stimuli, which consisted of patterns of suns, flowers, stars, etc. Very recently, Elazary and Itti (2008) investigated saliency maps and required their participants to label visual scences for saliency of low-level visual features like brightness, color or orientations. Because not all labels could have been predicted by these low-level features, the investigators stated that objects may be „salient for their meaning“. Thus, in the current experiment the Chinese character might have been more salient than the other objects, which served as neutral stimuli, or participants did not expect to be presented with Chinese characters. Friedman (1979) discovered that unexpected items are fixated

longer and subsequently are recalled better. If this is true for the effect found in control participants, the longer fixation would explain the slow-down of alternation rates. However, because no systematic data exist of how participants experienced the appearance of the character, this assumption is speculative and requires further research.

Alternations after the acoustic cue

It could also be stated that a bias to the acoustic cue would have affected the present results. Indeed, in neutral trials switching rates were decreased when the acoustic cue had been presented. The same decrease could be shown in the experimental group, but here, one expects a slow-down of alternations due to the activation of the learnt pair association. In comparison both groups did not differ. Thus, may the effect in the control participants be due to a bias of the acoustic signal per se? If this had been the case, one should also find a similar bias in target trials (with vs. without cue) – but here, no difference could be found. For the control group an implicit learning of cue and character association can be excluded, because the cue had been presented randomly. The control participants had been instructed to concentrate on their percepts and subsequent reportings, to ignore the interfering acoustic signal and to perform as accurate as possible. Thus, it seems most likely that after perceiving the interfering acoustic signal the control participants focussed their attention on the current percept in order to the instruction. Cognitive control was nessessary to focus their attention again on the current visual stimulus – this may be the time-consuming aspect which is mirrored in the reduction of alternation rates. However, because of the contradictory alternation-findings of neutral and target trials in control participants this, too, is not a completely satisfying explanation.

Phase duration

Had the former learnt paired association been able to sustain attention on the target stimulus during the rivalry trials? While in the control group (see fig. 10a) no difference to the non-targets appeared, the experimental group (see fig. 10b) perceived the non-target stimulus more often during the shortest phases (max. 2 seconds). This finding is not surprising, for short phases are known to reflect an unstable system (Mamassian et al., 2005). Concerning the longer phases the effect reversed. Here, attention sustained on target stimuli – this is true for

phases up to 10 seconds. In comparison the control participants` attention had been directed to the non-targets while the experimental participants showed longer sustained attentional phases on the targets, an effect which is confirmed when comparing the experimental and control group (see tables 5, 6). These results support the hypothesis that a previously learnt association increases sustained attention. Further support comes from neurophysiological studies. Desimone (1996) discusses findings in **I**nferior**T**emporal neurons in monkeys, which show a delay activity during anticipation of the second stimulus of a paired associate.

General Discussion

Two different paradigms (a perception-action and a learning paradigm) have been used to test their influence on binocular rivalry. In both experiments the initial onset and the absolute frequencies of target viewing were influenced by endogenously induced attention. The learning experiment further revealed long sustained attention phases on the target stimulus.

But was it really endogenous attention which caused the present finding? Both experiments used an acoustic cue which had been coupled with a certain stimulus in a previous task. Several studies show that an exogenous cue is effective to induce exogenous attention only for a limited time: Chong and Blake (2006) could not verify an exogenous effect after more than 450 ms after offset. Hancock and Andrews (2007) found that SOA (stimulus onset asynchrony) of 300 ms had the greatest influence, but the influence decreased with SOA. In contrast, in both current experiments SOA was 700 ms. In addition, one may ask if the cue per se would be perceived as a sudden-onset event and thus provoke exogenous attention. The answer is no, because it has been shown that central cues (which has to be interpreted due to the task demands) „do not effectively capture attention“ (Yantis, Jonides, 1990).

Additionally, Most and his colleagues (2005) found that when observers had adopted a specific attentional set and expect an informational event to be presented, this preparedness overrides the power of attentional capture.

Previous studies revealed conflicting results about the magnitude of endogenous (voluntary) attention on rivalry (Blake, 1988; Meng and Tong, 2004; Chong et al., 2005; Hancock and Andrews, 2007; the present results). Meng and Tong (2004) reported only a small effect of endogenous attention on rivalry. In contrast, my results, as that of Chong et al. (2005), and Hancock et al. (2007), revealed robust effects in both experiments. One possible reason for these differences is that participants in both experiments had been engaged in attention-demanding tasks. It may be that the weak effects Meng et al. (2004) had found were due to the fact that their participants had only been instructed „to attend“. The lack of a proper strategy could explain the difficulty in

sustaining attention. Furthermore, Chong, Tadin and Blake (2005) reported the better a participant's performance in a previous attention trial the longer the subsequent dominance phases of that certain target stimulus. Interestingly, participants in the two current experiments performed the attention tasks well and without mistakes. Despite both experiments revealed influences of endogenous attention on certain aspects of rivalry, all in all the results of the character experiment additionally revealed effects of sustained attention.

One possible explanation is a difference in the retrieval process due to the cue-target association. These associations are not effortless couplings of two events, instead, retrieval had turned out to implicate several cognitive processes. It could be shown that during preretrieval processing participants can operate differently on the information of a retrieval cue and thus can vary how a retrieval cue is processed. These processings are under voluntary control (see Rugg, 2004, for a detailed discussion). In the current character experiment the cue-target did not imply any uncertainties: cue and target had been identical across all trials. Thus, if participants adopted a special strategy during learning, the representation of the strategy had been valid over all trials. In the action intentionexperiment the cue might be considered as a signal for an intended action, but only under certain conditions (intact vs. broken tool), further, while the target category remained the same (intact tool), its individual items changed from trial to trial (hammer, screwdriver, etc.). Thus, in this experiment participants could have adopted different strategies (or, as Rugg (2004) calls it, retrieval orientations): they might have adopted associations between the cue and each tool. While this is a rather inefficient strategy, it seems more likely that the target has been represented as a category (intact tools). If so, participants had to check the target stimulus for matching this categorizing representation. This indeed seems likely, because no participant made any mistake. The disadvantage might be that the additional request for matching might have impaired its influence on rivalry (compared to the character experiment).

There is another conceivable explanation for the differences found between the current experiments. In the action intention experiment participants had to pick up a certain tool out of a box after each target trial. This instruction induced

selective attention on the tool's functional part. But perhaps rivalry performance might have been better, if observers had been required to *act* on the tools. When requested to pick the tool out of the box, recognition is required. Recognition of an object such as a tool „automatically potentiates components of the actions they afford" (Tucker, Ellis, 1998). It is possible that this immanent information of a tool representation is less powerful to influence subsequent rivalry than the representation of an intended action. Support of this view comes from the proposal that in addition to a certain action schema a body schema is also activated when carrying out a certain action (Lewis, 2006) – a proposal which is supported by neuropsychological findings, namely in patients with apraxia (Goldenberg, 1995; Goldenberg, 1998).

One can argue that the action intention experiment did not provide the same results because of a too demanding task. This is unlikely, because participants performed accurately and did not make any mistakes. So, maybe the task of touching, identifying the tools and picking up the right one out of the box did not strengthen enough the required representation, even though common visual-haptic processing in the inferior posterior temporal gyrus had been evidenced (Lepage et al., 2001). Maruya and his colleagues (2007) also used the action-perception paradigm (Prinz, Hommel, 2002) to test its influence on rivalry. But their participants had to perform movements with the computer mouse *while* having been presented with one congruently moving rival stimulus. The authors proposed the strong effects on the dominance durations and reduction on suppression phases might be attributed to the finding that these visually guided actions are processed in the dorsal pathway, specialized for visuo-motor processing (see chapter 1.1), a proposal which received support by a study of Schubö, Prinz, Aschersleben (2004). Schubö et al. (2004) found evidence of shared representations for perception and action control. Thus, possibly the planning of an action during the rivalry trial resulted in a pretuning of the requested feature-maps, but this representation was not sufficient to additionally shorten the suppression phases that were found by Maruya et al. (2007). However, both paradigms had proved to influence certain aspects of rivalry via endogenously driven attention.

In both experiments the target stimuli (character and intact tool respectively) had been the first to be perceived in experimental groups and further an advantage for both could be shown in sustained rivalry.

Several studies present robust influences of both exogenous and endogenous attention on rivalry onset and sustained rivalry (Ooi and He, 1999; Mitchell et al., 2004; Chong and Blake, 2006 and Carter and Cavanagh, 2007). Chong and Blake (2006) used a feature tracking task to bundle endogenous attention on a certain property of one stimulus.

Endogenously driven attention turned out to influence rivalry onset. In both, character learning and action-perception experiments, endogenous attention provided the same advantage. Chong and his colleague (2006) come to the conclusion that attention increases the effective contrast of the attended stimulus (see Carrasco et al., 2004, discussed above). Because psychophysical experiments may be vulnerable for psychological reasons (see Norton et al., 2002, for detailed discussions), very recently Schneider and Komlos (2008) replicated the Carrasco et al. study, but found a fundamental difference when changing the type of decision to be made: while a comparative judgement can be biased, an equality judgement resists the bias. It is conceivable that attention to an object and its subsequent report includes multiple mechanisms based on the neuronal, psychophysical, and/or psychological level which may be vulnerable to be biased. Thus, even though I am aware of the fact that the underlying mechanism of attention on certain stimuli may be more complicated than originally assumed – I agree with the assumption that attention enhances the apparent contrast of the attended item. But where exactly in the visual pathway does attention alter the information processing of an object, and how is it driven to finally influence target objects in rivalry?

Endogenous attention such as that induced in the current experiments are known to act top-down. Corbetta and Shulman (2002) review psychological, neurophysiological and physiological evidence for two partially segregated attentional networks: one of which is specialized to detect behaviorally relevant objects includes the temporoparietal and inferior frontal cortex, the other of which is involved in preparation and applying top-down selection for stimuli and responses. The latter system includes parts of the intraparietal cortex and

superior frontal cortex. Banich et al. (2000) found that dorsolateral prefrontal activation significantly increased when an attentional set was difficult to impose or an automatic response had to be overriden. Corbetta and Shulman (2002) postulate an overlap of the dorsal frontoparietal network concerning attention to locations and objects. In a fMRI-study Giesbrecht et al. (2003) tested the generality of the frontoparietal network in attentional control by inducing spatial and non-spatial attention. The investigators revealed subregions reacting on both and those regions highly specific for controlling spatial selective attention. However, how does a top-down attentional brain state influence visual processing? Top-down effects affect features, object categories, objects, surfaces, and augment or multiply responses, sharp neuronal tuning curves, control contextual influences, or modulate plasticity (Gilbert and Sigman, 2007) via feedback connections. Attention operates at various stages in the visual system such as the LGN or higher levels such as V4 or TEO (Kastner, Pinsk, 2004), but its power increases gradually the higher the level of processing (Treue, 2003; but see Gilbert and Sigman, 2007). In the present experiments participants had learnt an acoustic cue-visual target association and had been requested to attend to an intact tool to later carry out an action.

What might have been the common underlying mechanisms of guiding the participants' attention to solve the tasks? One model of how the brain controls attention is that a cognitive control system in dorsolateral prefrontal cortex (DLPFC) receives information from the anterior cingulate cortex which monitors conflicts between response tendencies. (These response tendencies may be due to the retrieval orientations based on a certain cue discussed above.) The DLPFC subsequently influences perceptual processing through attentional biases (Egner, Hirsch, 2005), an assumption which is supported by brain imaging. In a fMRI-study Egner and Hirsch (2005) revealed clusters of activation in the right DLPFC (BA 46), the right middle temporal gyrus and left anterior insula due to cognitive control and selective attention.

It is important to note that the acoustic cues presented to the participants did not contain any goal-related information per se. Instead, participants were to remember the task when presented with the cue. Thus, the mediating variable between the cue and control of attention was working memory. Humans

translate the task goals into attentional control settings which help them to specify relevant stimulus features and additionally appropriate responses (Pratt and Hommel, 2003). Sensory information and attentional modulation integrate into a saliency map of the „visual environment that flags regions of interest in the retinal image“ (Treue, 2003). In other words: saliency refers to bottom-up differences of objects in relation to other objects of the visual environment. In contrast, in the current experiments the participants had to act on a relevant object (character) or object parts (functional tool part). Bottom-up saliency and top-down sources are known to build an integrated representation of priority (Fecteau, Munoz, 2006) which guides goal-driven visual information processing. It is likely that participants of the current experiments built priority maps due to the task goal respectively, an assumption which is supported by the findings of Shomstein and Yantis (2002). However, even though the „preliminaries“ just discussed had been the same for the two experiments, the results differ, at least in part.

However, the current experiments showed that endogenous attention influences the initial percept of a previously learnt stimulus, represented as a whole object, and on certain features of a stimulus, induced by the intention to act. How do the results fit into models of binocular rivalry? As described in the former sections bottom-up vs top-down or low-level vs high-level mechanisms in the visual pathways during rivalry lead to two major theories. These competing views had been challenged recently and a „hybrid model“ had been proposed (Blake, Logothetis, 2002; Tong, Meng and Blake, 2006). Blake and Logothetis (2002) point out that dominance and suppression phases are not to be considered as two sides of the same coin, but instead differ in their determinants. Even though I used a learning and a perception-action paradigm for the first time, the attentional influences on the initial percept and dominance phases in sustained rivalry are in line with others, as discussed above. While dominance seems to be influenced more easily (see Chong et al., 2005, among others), suppression turned out to be more resistant to attentional modulations (Mitchell et al., 2004, Chong and Blake, 2005). However, in the character learning experiment the target object revealed a weak effect of reduced suppression phases, while no such effect could be found in the action intention experiment.

Thus, according to the differences of these two experiments discussed so far, it would be worth to further investigate if successive changes of the outlined variables would strengthen the effects. While Blake and Logothetis (2002) modelled the different aspects of rivalry, Tong et al. (2006) explicate the possible neuronal underlyings, because human neuroimaging and psychophysical studies revealed interactions of rival stimuli on several brain sites. Thus, the neuronal model takes into account inhibitory monocular and binocular connections (to account for interocular or pattern competition), excitatory monocular and binocular connections (to account for eye-based grouping, low-level and high level pattern grouping), and feedback connections (to account for feedback grouping and top-down feedback excitation). Excitatory feedback connections are indispensable to explain the initial percept and the repetitive target dominance effects of endogenous attention found in the current experiments. Obviously, it did not play a role if a whole object (the character) or certain stimulus features (functional part of the tool) had been subject to attention. For rivalry onset (Chong and Blake, 2005) and the repetitive target dominance phases it is in line with current research to assume that indeed an increase of apparent contrast helped the target stimuli to become dominant first. These postulates help one to understand how rivalry and its attentional influences might be implemented into neural processing, but they leave open the question how a certain selection is carried out. Together with recently used paradigms such as a feature tracking task (Chong and Blake, 2006), and concurrent action (Maruya et al., 2007), the introduction of the two paradigms as used in the current experiments, is a promising starting point to discover what kind of cognitive structures have the power to influence aspects of rivalry and what the underlying neuronal mechanisms are.

Conclusion

Two new paradigms (perception-action, learning) have been applied to binocular rivalry. For both experiments a top-down driven influence on the initial onset and the frequencies of target stimuli could have been shown, even though the visual stimuli had been a part of a cognitive task. Both applied paradigms provide ideas for further rivalry research. An interesting follow-up study of the learning experiment may address the questions whether the level of learning plays a critical role, and whether the influences on single rivalry parameters change with expertise. The weak effects on suppression phases found in the learning experiment also deserve further investigation.

The action intention experiment revealed an interaction between action intentions and binocular rivalry via top-down attention. Two questions emerge from this finding: Which features of these action intentions are essential to influence rivalry? And how much attention is needed to build this interaction? The answers would help to build a coarse frame for understanding the interactions in more detail.

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